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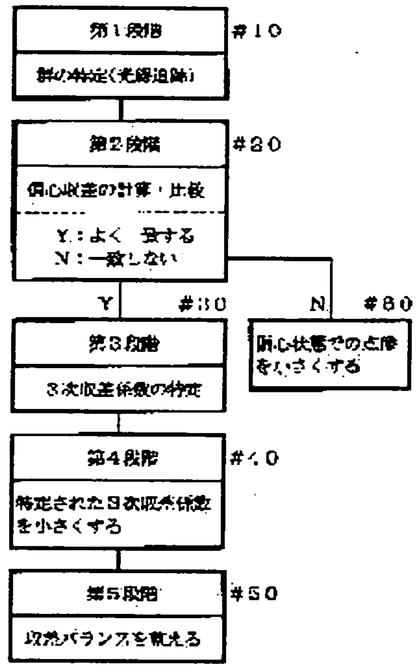
(54) OPTICAL SYSTEM AND ITS MANUFACTURE AND ECCENTRICITY ERROR SENSITIVITY REDUCTION DESIGNING METHOD

(57)Abstract:

PROBLEM TO BE SOLVED: To provide the optical system which has excellent optical performance and its manufacture and eccentricity error sensitivity reduction designing method by suppressing eccentric aberration due to a manufacture error small.

SOLUTION: An arbitrary optical system has a 1st stage 10 wherein a group which causes a manufacture problem since eccentricity error sensitivity is relatively large is specified, a 2nd stage 20 wherein the eccentricity error is calculated by using the eccentric aberration coefficient of the specified group and the obtained eccentricity error is compared with actual eccentric aberration obtained by light beam tracking, a 3rd stage 30 wherein the tertiary aberration coefficient of a main factor making the eccentricity error sensitivity large is specified when it is judged that the eccentric aberration matches the actual one well, a 4th stage 40 wherein the tertiary aberration coefficient is made small, and a 5th stage 50 wherein aberration balance is so controlled that the total performance is held nearly equal to that before the designing.



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CLAIMS

[Claim(s)]
[Claim 1] The 1st step which specifies the group which consists of at least one lens side which poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. The 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step so that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step, and optical system designed as be alike.
[Claim 2] Optical system characterized by for optical system according to claim 1 being a zoom lens, and the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.
[Claim 3] Optical system according to claim 1 which designs and changes so that magnitude of point distribution in the eccentric condition may be minimum-ized when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.
[Claim 4] Optical system according to claim 1 to which a design in said 4th step is characterized by being addition of the lens by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 5] Optical system according to claim 1 to which a design in said 4th step is characterized by being addition of the aspheric surface by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 6] Optical system according to claim 1 to which a design in said 5th step is characterized by being addition of the lens by the side of a body rather than the group specified in said 1st step.
[Claim 7] Optical system according to claim 1 to which a design in said 5th step is characterized by being addition of the aspheric surface by the side of a body rather than the group specified in said 1st step.
[Claim 8] Optical system according to claim 1 characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system.
[Claim 9] The 1st step which specifies the group which consists of at least one lens side which poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. So that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step The manufacture approach of the optical system characterized by having the 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step.
[Claim 10] The manufacture approach of the optical system according to claim 9 characterized by for said optical system being a zoom lens and the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.
[Claim 11] The manufacture approach of the optical system according to claim 9 characterized by designing so that magnitude of point distribution in the eccentric condition may be minimum-ized when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.
[Claim 12] The manufacture approach of optical system according to claim 9 that a design in said 4th step is characterized by being addition of the lens by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 13] The manufacture approach of optical system according to claim 9 that a design in said 4th step is characterized by being addition of the aspheric surface by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 14] The manufacture approach of optical system according to claim 9 that a design in said 5th step is characterized by being addition of the lens by the side of a body rather than the group specified in said 1st step.
[Claim 15] The manufacture approach of optical system according to claim 9 that a design in said 5th step is characterized by being addition of the aspheric surface by the side of a body rather than the group specified in said 1st step.
[Claim 16] The manufacture approach of the optical system according to claim 9 characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system.
[Claim 17] The 1st step which specifies the group which consists of at least one lens side which poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. So that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step

The eccentric-error sensibility reduction design approach characterized by having the 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step.
[Claim 18] The eccentric-error sensibility reduction design approach according to claim 17 characterized by for said optical system being a zoom lens and the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.
[Claim 19] The eccentric-error sensibility reduction design approach according to claim 17 characterized by designing so that magnitude of point distribution in the eccentric condition may be minimum-ized when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.
[Claim 20] The eccentric-error sensibility reduction design approach according to claim 17 that a design in said 4th step is characterized by being addition of the lens by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 21] The eccentric-error sensibility reduction design approach according to claim 17 that a design in said 4th step is characterized by being addition of the aspheric surface by the side of an image rather than the group specified in said 1st step, or its group.
[Claim 22] The eccentric-error sensibility reduction design approach according to claim 17 that a design in said 5th step is characterized by being addition of the lens by the side of a body rather than the group specified in said 1st step.
[Claim 23] The eccentric-error sensibility reduction design approach according to claim 17 that a design in said 5th step is characterized by being addition of the aspheric surface by the side of a body rather than the group specified in said 1st step.
[Claim 24] The eccentric-error sensibility reduction design approach according to claim 17 characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Field of the Invention] This invention relates to optical system with the eccentric-error sensibility small in more detail equipped with the applicable features to all optical system (for example, photography optical system of a camera), its manufacture approach, and the eccentric-error sensibility reduction design approach about optical system, its manufacture approach, and the eccentric-error sensibility reduction design approach.
[0002]
[Description of the Prior Art] For example, in manufacture of optical system, if eccentric errors, such as parallel eccentricity and inclination eccentricity, arise in a part of optical system, eccentric aberration will occur. The error sensibility of this eccentric aberration becomes one factor which makes manufacture of optical system difficult. Conventionally, a general thing reduces the error sensibility of the part of a power ratio by optical system with small eccentric-error sensibility by making small power of the lens group which poses a problem. Moreover, in JP,8-220435,A, in order to reduce the sensibility to the eccentricity of the aspheric surface, the zoom lens which specified the size relation between the criteria radius of curvature of the aspheric surface and deviation is proposed so that the image surface inclination generated with the relative eccentricity of the mutual lens side of both aspheric lenses may become below a predetermined value.
[0003]
[Problem(s) to be Solved by the Invention] In the former optical system, unless changing power sharply is carried out, eccentric-error sensibility cannot be reduced sharply. On the other hand, although only the relative eccentricity of the mutual lens side of both aspheric lenses is prescribed by the latter zoom lens, whenever error sensibility is the aspheric surface, it is not necessarily large. For example, if radius of curvature is the small large field of deviation even if it is the aspheric surface, the error sensibility to eccentricity is small, and conversely, if it is the field where radius of curvature is small even if it is the spherical surface, the error sensibility to eccentricity is large. Therefore, even if it reduces only the error sensibility to the eccentricity of both aspheric lenses, error sensibility to the eccentricity of the whole optical system cannot necessarily be reduced.
[0004] This invention is made in view of these points, clarifies formation of eccentric aberration in analyzing the eccentric aberration produced with eccentricity, suppresses small the eccentric aberration generated with a manufacture error, and aims at offering the optical system which has good optical-character ability, its manufacture approach, and the eccentric-error sensibility reduction design approach.
[0005]
[Means for Solving the Problem] In order to attain the above-mentioned purpose, the optical system of the 1st invention The 1st step which specifies the group which consists of at least one lens side which poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. So that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step It has the 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step, and composition designed as be alike.
[0006] In the configuration of invention of the above 1st, the optical system is a zoom lens and optical system of the 2nd invention is characterized by the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.
[0007] In the configuration of invention of the above 1st, the optical system of the 3rd invention has composition designed so that magnitude of point distribution in the eccentric condition might be minimum-ized, when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.
[0008] Optical system of the 4th invention is characterized by being addition of the lens by the side of an image in the configuration of invention of the above 1st rather than the group as which the design in said 4th step was specified in said 1st step, or its group.
[0009] Optical system of the 5th invention is characterized by being addition of the aspheric surface by the side of an image in the configuration of invention of the above 1st rather than the group as which the design in said 4th step was specified in said 1st step, or its group.
[0010] Optical system of the 6th invention is characterized by being addition of the lens by the side of a body in the configuration of invention of the above 1st rather than the group as which the design in said 5th step was specified in said 1st step.
[0011] Optical system of the 7th invention is characterized by being addition of the aspheric surface by the side of a body in the configuration of invention of the above 1st rather than the group as which the design in said 5th step was specified in said 1st step.
[0012] Optical system of the 8th invention is characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system in the configuration of invention of the above 1st.
[0013] The 1st step which specifies the group which consists of at least one lens side where the manufacture approach of the

optical system the 9th invention poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. It is characterized by having the 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step so that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step.

[0014] In the configuration of invention of the above 9th, said optical system is a zoom lens and the manufacture approach of the optical system the 10th invention is characterized by the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.

[0015] In the configuration of invention of the above 9th, the manufacture approach of the optical system the 11th invention is characterized by designing so that magnitude of point distribution in the eccentric condition may be minimum-ized, when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.

[0016] The manufacture approach of the optical system the 12th invention is characterized by being addition of the lens by the side of an image in the configuration of invention of the above 9th rather than the group as which the design in said 4th step was specified in said 1st step, or its group.

[0017] The manufacture approach of the optical system the 13th invention is characterized by being addition of the aspheric surface by the side of an image in the configuration of invention of the above 9th rather than the group as which the design in said 4th step was specified in said 1st step, or its group.

[0018] The manufacture approach of the optical system the 14th invention is characterized by being addition of the lens by the side of a body in the configuration of invention of the above 9th rather than the group as which the design in said 5th step was specified in said 1st step.

[0019] The manufacture approach of the optical system the 15th invention is characterized by being addition of the aspheric surface by the side of a body in the configuration of invention of the above 9th rather than the group as which the design in said 5th step was specified in said 1st step.

[0020] The manufacture approach of the optical system the 16th invention is characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system in the configuration of invention of the above 9th.

[0021] The eccentric-error sensibility reduction design approach of the 17th invention The 1st step which specifies the group which consists of at least one lens side which poses a manufacture top problem in the optical system of arbitration since eccentric-error sensibility is relatively large. The 2nd step which performs the comparison with the eccentric aberration which calculated eccentric aberration using the eccentric aberration coefficient of the group specified in this 1st phase, and was acquired by this count, and actual eccentric aberration. The 3rd step which specifies the 3rd aberration coefficient which serves as a key factor which enlarges said eccentric-error sensibility when it is judged that the eccentric aberration acquired by said count and actual eccentric aberration are well in agreement as a result of a comparison in this 2nd phase. It is characterized by having the 5th step which performs the design which prepares the aberration balance changed with the design in said 4th step so that it may be maintained to the same extent as the 4th step which performs the design which makes small the 3rd aberration coefficient specified in this 3rd phase, and the condition before said design of totality ability in the 4th step.

[0022] In the configuration of invention of the above 17th, said optical system is a zoom lens and the eccentric-error sensibility reduction design approach of the 18th invention is characterized by the group specified in said 1st step being biggest zoom group of eccentric-error sensibility.

[0023] In the configuration of invention of the above 17th, the eccentric-error sensibility reduction design approach of the 19th invention is characterized by designing so that magnitude of point distribution in the eccentric condition may be minimum-ized, when it is judged that the eccentric aberration acquired by said count differs from actual eccentric aberration greatly as a result of said comparison in the 2nd step.

[0024] The eccentric-error sensibility reduction design approach of the 20th invention is characterized by being addition of the lens by the side of an image in the configuration of invention of the above 17th rather than the group as which the design in said 4th step was specified in said 1st step, or its group.

[0025] The eccentric-error sensibility reduction design approach of the 21st invention is characterized by being addition of the aspheric surface by the side of an image in the configuration of invention of the above 17th rather than the group as which the design in said 4th step was specified in said 1st step, or its group.

[0026] The eccentric-error sensibility reduction design approach of the 22nd invention is characterized by being addition of the lens by the side of a body in the configuration of invention of the above 17th rather than the group as which the design in said 5th step was specified in said 1st step.

[0027] The eccentric-error sensibility reduction design approach of the 23rd invention is characterized by being addition of the aspheric surface by the side of a body in the configuration of invention of the above 17th rather than the group as which the design in said 5th step was specified in said 1st step.

[0028] The eccentric-error sensibility reduction design approach of the 24th invention is characterized by performing a design in the 4th step and said 5th step, without changing power arrangement of the whole system in the configuration of invention of the above 17th.

[0029]

[Embodiment of the Invention] Hereafter, the optical system which carried out this invention, its manufacture approach, and the eccentric-error sensibility reduction design approach are explained, referring to a drawing. First, the property of the eccentric aberration seen from the derivation and the aberration coefficient of eccentric aberration by the aberration coefficient is explained.

[0030] Derivation>> of the eccentric aberration by <<aberration coefficient If location gap is caused perpendicularly or a part of optical system (for example, a field, a lens, a lens group) inclines to it to an optical axis, optical-character ability will deteriorate with the eccentricity (namely, when eccentric errors, such as parallel eccentricity and inclination eccentricity, occur). This is because eccentric aberration occurs in optical system with eccentricity. The error sensibility of this eccentric aberration

becomes one factor which makes manufacture of optical system difficult. The main things are piece dotage aberration and shaft top comatic aberration in eccentric aberration.
[0031] "Piece dotage aberration" is the phenomenon in which the image surface becomes unsymmetrical about an optical axis. That is, when eccentricity occurs, it is the phenomenon in which a forward field angle differs in an image surface location from a negative field angle. Piece dotage aberration is usually estimated by the average of the difference in the paraxial image surface location of the chief ray of the field angle of about 70 percent of a screen vertical angle. On the other hand, "shaft top comatic aberration" is the phenomenon in which the axial Uemitsu bundle becomes unsymmetrical about a chief ray. According to the optical system which should be the symmetry of revolution, the point on a shaft also usually serves as the symmetry of revolution. However, if eccentricity occurs in a part of optical system, symmetric property will collapse and the image engine performance will deteriorate greatly. Shaft top comatic aberration is usually estimated by the difference of the beam-of-light location average of the top ZONARU beam of light (Upper) on the shaft of about 70 percent of the path of a shaft top effective diameter, and a bottom ZONARU beam of light (Lower), and a shaft top chief ray location. The aberration of the optical system to which eccentricity exists in below is examined, and the two above-mentioned eccentric aberration is derived using an aberration coefficient.
[0032] <3rd aberration expansion of the optical system in which eccentricity exists> The relation of a basic optical system and coordinate is shown in drawing 1 . In drawing 1 (A) and (B), OS is a refractive index [in / IS / a body flat surface and / an image plane and PS1 an exit pupil side, a refractive index / in / SF / an image side principal plane (H': image side principal point) and / 2 / body side principal plane (H: body side principal point) and / HS/ 1 / HS/ front-face / of optical system /, and SR, and / in N / object space /, and N', and / in PS2 / image space]. [an entrance pupil side] [rear face of optical system]
[0033] The X-axis is set as this by using the optical axis of optical system in case eccentricity does not exist as a reference axis AX, and a Y-axis and the Z-axis are taken at right angles to this. And the coordinate of the probe index of the beam of light on (Y, Z), and the entrance pupil side PS 1 is made into (Y*, Z*) for the coordinate of the object point OP, and "'" is attached and expressed to the coordinate of the image space corresponding to these. However, in developing the transverse aberration of the beam of light on an image plane IS to the 3rd BEKI series, a definition is given, using the following polar coordinate as a coordinate of the object point OP and the probe index of the beam of light on the entrance pupil side PS 1.
tanomega-cosphiomega**Y/g$ — (1A) tanomega-sinphiomega**Z/g$ — (1B) R-cosphiR**(g$/g) -Y* — (2A) R-sinphiR**(g$/g) -Z* — (2B) [0034] As drawing 1 shows, the straight lines to which g and g$ connects the distance from the entrance pupil side PS 1 and the body side principal plane HS1 to the body flat surface OS, and omega connects the object point OP and the body side principal point H, respectively are a reference axis AX and the angle to make, and phiR is the AJIMUSU angle in the entrance pupil radius to which phiomega converted the AJIMUSU angle (azimuth) and R on the body side principal plane HS1. "— a conversion inclination [in / in alpha / the object space of a paraxial shaft top MAJINARU beam of light] since " expresses image space and "#" expresses the chief ray outside a shaft, a conversion inclination [in / in alpha# / the object space of the chief ray outside a paraxial shaft], a conversion inclination [in / in alpha' / the image space of a paraxial shaft top MAJINARU beam of light], and 'alpha' # are the conversion inclinations in the image space of the chief ray outside a paraxial shaft.
[0035] If transverse aberration in case eccentricity exists is developed to BEKI series noting that optical system consists of k elements, deltaZ' will become transverse aberration deltaY', and the following formulas (3A) and the form shown in (3B) (beta: lateral magnification). The 3rd aberration coefficients corresponding to spherical aberration, comatic aberration, astigmatism, the PETTSU bar sum, and distortion aberration are I, II, III, P, and V, respectively, and a characteristic mu is an element number and are alpha'= alpha'k and alpha'#=alpha'#k. in addition, the display using a summation symbol sigma shall be performed as shown in the following examples (the following — the same .)
[0036]
[External Character 1]
$$\sum_{\mu=1}^{k} \quad : \quad (\mu=1\rightarrow k)\,\Sigma$$
[0037]
deltaY'**Y'-beta-Y = -[1/(2andalpha')], {(N-tanomega) 3 and cosphiomega (mu=1->k), sigmaVmu + R, 2, [2, cos(phi R-phi omega), cosphiomega, and(mu=1->k) sigmaIIImu + cosphiRand(mu=1->k) sigma(IIImicro+Pmu)] + R2-(N-tanomega) - [2 and cosphiR-cos (phi R-phi omega) +cosphiomega] -(mu=1->k) sigmaIImu + R3, cosphiR, and(mu=1->k) sigmaImu} + {Addition term by eccentricity (Y component)} — (3A) deltaZ'**Z'-beta-Z = -[1/(2andalpha')], {(N-tanomega) 3 and sinphiomega (mu=1->k), sigmaVmu + R, 2, [2, cos(phi R-phi omega), sinphiomega, and(mu=1->k) sigmaIIImu + sinphiRand(mu=1->k) sigma(IIImicro+Pmu)] + R2-(N-tanomega) - [2 and sinphiR-cos (phi R-phi omega) +sinphiomega] -(mu=1->k) sigmaIImu +R3, sinphiR, and(mu=1->k) sigmaImu} + {the addition term (Z component) by eccentricity} — (3B)
[0038] these formulas (3A) and (3B) — setting — {} of the beginning of the right-hand side -- inside is a term showing the aberration of optical-system original in case eccentricity does not exist, and if eccentricity exists, it will become the form where the aberration term generated with eccentricity joins it. "Inclination eccentricity" which inclines [as opposed to / when the element (you may be the multicomputer system which consists of two or more pages even if it is a single side.) of the arbitration in optical system carries out eccentricity / in the eccentricity / the reference axis AX of optical system] to the "parallel eccentricity" which carries out a parallel displacement in the perpendicular direction, and a reference axis AX, and ******. Each of those effects is expressed as an addition term of the above-mentioned formula (3A) and the right-hand-side last of (3B).
[0039] <Derivation of an parallel eccentricity aberration coefficient> Drawing 2 (A) shows the condition that element (it is called "** nu element" below and optical axis of ** nu element is expressed with AXnu.) Dnu of eye nu watch of the arbitration in optical system carried out parallel eccentricity only of minute amount Enu in the perpendicular direction of Y to the reference axis AX of optical system. The addition terms delta Y (Enu) and delta Z (Enu) of the aberration coefficient by this parallel eccentricity are expressed with the following formulas (4A) and (4B).
deltaY(Enu) =-[Enu/(2 and alpha'k)] -{(deltaE) nu + N-tanomega2- [(2+cos2phiomega) -(VE1) nu-(VE2) nu] + 2andR-(N-tanomega) -[(2 and cos(phi R-phi omega)+cos (phi R+phi omega)) and(IIIE)nu + CosphiR-cosphiomega- (PE) nu] + R2-(2+cos2phiR) -(IIE)nu} — (4A) deltaZ(Enu) =-[Enu/(2 and alpha'k)], {(N-tanomega) 2, sin2phiomega, and (VE1) nu + 2andR-(N-tanomega) - [sin(phi R+phi omega), (IIIE)nu +sinphiR-cosphiomega, and (PE) nu] +R2andsin2phiR-(IIE) nu} — (4B) [0040] However, an eccentric aberration coefficient is defined by the following formula (4C) - (4H).
(deltaE) nu=-2- (alpha'nu-alphanu) — (4C) (VE1) nu= {[alpha'nu (micro=nu+1->k) and sigmaVmu]-[alphanu and (micro=nu->k)

sigmaVmu]} - {[alpha'#nu-(micro=nu+1->k) sigmaIIImu]-[alpha#nu and (micro=nu->k) sigmaIIImu]}
— (4D)
(VE2) nu=[alpha'#nu (micro=nu+1->k) and sigmaPmu]- [alpha#nu (micro=nu->k) and sigmaPmu] — (4E) (IIIE) nu= {alpha'nu. [sigmaIIImu]-[alphanu. and (micro=nu->k) sigmaIIImu]} - {[alpha'#nu-(micro=nu+1->k) sigmaIImu]-[alpha#nu and (micro=nu->k) sigmaIImu]} — (4F) (PE) nu=[alpha'nu (micro=nu+1->k) and sigmaPmu]- [alphanu (micro=nu->k) and sigmaPmu] — (4G) (IIE) nu= {alpha'nu. [sigmaIImu]-[alphanu. and (micro=nu->k) sigmaIImu]} - {[alpha'#nu (micro=nu+1->k) and sigmaImu]-[alpha#nu and (micro=nu->k) sigmaImu]} — (4H) [0041] The above-mentioned formula (4C) - (4H) eccentricity aberration coefficient expresses the effect by eccentricity, and serves to pay the defect of the image formation of the following contents by proxy, respectively. Moreover, since eccentricity Enu starts the whole right-hand side so that a formula (4A) and (4B) may show, the amount of the aberration generated with eccentricity is proportional to Enu.
nu: (deltaE) Prism operation (strike slip of an image).
(VE1) nu and nu(VE2):rotation — unsymmetrical distortion.
(IIIE) nu and (PE) nu:rotation — the inclination of unsymmetrical astigmatism and the image surface.
(IIE) the rotation which appears also on nu:shaft — unsymmetrical comatic aberration.
[0042] Although - (4H) shows the case where only formula (4A) and ** nu element Dnu carries out parallel eccentricity If this ** nu element Dnu consists of a single side, when two or more field i-j carries out parallel eccentricity, (that is, when the lens group which carries out eccentricity consists of the i-th page to the j-th page) Since eccentricity Ei-Ej of each field i-j which carries out eccentricity is equal, as formula:(deltaE) i-j=(nu=i->j) sigma [-2- (alpha'nu-alphanu)] shows, an aberration coefficient can be treated as the sum. And formula:(deltaE) i-j=-2- (alpha'j-alphai) is obtained from alpha'nu=alpha nu+1.
[0043] About other aberration coefficients, the term in the middle of sigma disappears similarly. With PE (PE) i-j=(nu=i->j) sigma {alpha'nuand(micro=nu+1->k) sigmaPmu-alphanu (micro=nu->k), and sigmaPmu] = Alpha'jand(micro=j+1->k) sigmaPmu-alphai (micro=i->k), sigmaPmu = alpha'j-alpha — R-alphaiand [i, sigmaPmu-alpha i, and (micro=i->j) sigmaPmu =(alpha'j-alphai) -(P)] (P) D — the lens group (it is also called "an eccentric group" below.) carried out (P) R=(micro=j+1->k) sigmaPmu:eccentricity here The sum of the aberration coefficient P of the group (henceforth "******") which consists of all the lens sides located in an image side, (P) D=(micro=i->j) sigmaPmu : It is the sum of the aberration coefficient P of an eccentric group. Therefore, sigma of an eccentric aberration coefficient is expressed by sum {()R of the aberration coefficient of ******. It is expressed as] by sum {()D of the aberration coefficient of an eccentric group, it can come out and,}, can express.
[0044] [Piece dotage aberration], next piece dotage aberration are explained. meridional ** of a formula (4A) and (4B) to astigmatism, and [primary term of R phiR=0 of deltaY'] — xg'$k — it is — sagittal one — [Primary term of R phi R=pi of deltaZ' / 2] — it is xg'$k. Therefore, the meridional piece dotage deltaMnu is expressed with the following formulas (5A). Here, a formula (5B) is obtained from alpha'k=N'k/g'$k and phiomega=0.
deltaMnu=-[E nu-g'$k/] and2- (2 and alpha'k) (N-tanomega) - [(2 and cos(phiomega)+cos (phiomega)) -(IIIE)nu+cos(phiomega) and (PE) nu] — (5A) deltaMnu=- Enu-(g'$k2-/N'k) -(N-tanomega) - [3and(IIIE) nu+(PE) nu] — (5B) [0045] Since it is g '$k->floor line (floor line: focal distance of the whole system) and N-tan omega=Y' / floor line (Y': image quantity) when the object point OP is made into infinite distance, the formula (5C) showing meridional piece dotage delta M"nu is obtained. Similarly, the formula (5D) showing sagittal piece dotage delta S"nu is obtained.
delta M"nu = -E nu-floor line-Y '3and(IIIE) -[nu+(PE) nu] —(5C) delta S"nu =-E nu-floor line-Y' - [(IIIE) nu+(PE) nu] — (5D) [0046] Although the above is the case where a ** nu side carries out eccentricity, when a lens group (it consists of the i-th page at the j-th page) carries out eccentricity, sigma is taken, and the formula (5E) showing meridional piece dotage (deltaM") i-j and sagittal piece dotage (deltaS") i-j and (5F) are obtained. Here, eccentricity is set to E.
(deltaM") i-j=-E-floor line-Y'3and(IIIE) -[i-j+(PE) i-j] —(5E) (deltaS") i-j=-E-floor line-Y' - [(IIIE) i-j+(PE) i-j] -- (5F) It corrects. The eccentric aberration coefficient of a block (lens group) is expressed with the following formulas (5G) and (5H) about meridional one and sagittal each.
3and (II) 3, and(III) 3, [R+(P) R]-alphai and [D+(P) D]- (alpha'# j-alpha#i) -[R]+ alpha#i - (IIIE) (alpha'j-alphai) [3and (II) D] — (5G) [(IIIE) — i-j — + -- (— PE —) — i-j --] — = (alpha'j-alphai) - [(III) — R — + -- (— P —) — R --] - alpha — i - [(III) — D — + — (— P —) — D —] - (alpha'# j-alpha#i) - [— (— II —) — R —] — + — alpha#i - [— (— II —) — D —] — [— 5H) —
0047] [Shaft top comatic aberration], next shaft top comatic aberration are explained. Shaft top comatic aberration is the average of the difference of axial Uemitsu's Upper, and the chief ray location of Lower, as mentioned above. therefore — from the coma (deltaYL) nu of the coma (deltaYU) nu and Lower of Upper by eccentricity — {(6A) —} (6B) and shaft top comatic-aberration (AXCM) nu shown in a formula (6C) are drawn.
nu= (deltaYU) (deltaY) omega= 0, (phiR=0)- (deltaY) =-[Enu/(2 and alpha'k)] -R2, 3, and (IIE) nu (omega= 0, R= 0) — (6A) (deltaYL) — nu — =(deltaY) (omega= 0, phi R=pi)-(deltaY) (omega= 0, R= 0) =-[Enu/(2 and alpha'k)] -R2, 3, and (IIE) nu —(6B) (AXCM) nu= [(deltaYU) nu+(deltaYL) nu] /2=-[Enu/(2 and alpha'k)] -R2, 3, and (IIE) nu — (6C) [0048] It will be set to 1-/alpha'k ->-floor line if the object point is made into infinite distance. moreover, the relation between R and FNO (f number of the whole system) is expressed with formula:R=[floor line/(2, FNO)] xkappa (here — it is — kappa:pupil split ratio — it is usually 0.7.). Therefore, shaft top comatic-aberration (AXCM") nu is expressed with a formula (6D).
(AXCM") Nu=Enu-(3, kappa2, and floor line3)/(8, FNO2) and(IIE)nu — (6D) [0049] Although the above is the case where a ** nu side carries out eccentricity, when a lens group (it consists of the i-th page at the j-th page) carries out eccentricity, sigma is taken, and a formula (6E) is obtained. However, the eccentric aberration coefficient of a block is expressed with a formula (6F).
(AXCM") i-j=E-[(3, kappa2, and floor line3)/(8, FNO2)] and (IIE) i-j — (6E) (IIE) -(II) R-alpha i and (II) D-(alpha'# j-alpha#i) -(I) R+alpha#i and [i-j=(alpha'j-alphai)] (I) D — (6F) [0050] <Derivation of an inclination eccentricity aberration coefficient> As for drawing 2 (B), only include-angle epsilonnu shows [** nu element Dnu] the condition of having inclined, focusing on Point C to the reference axis AX of optical system. The addition terms delta Y (epsilonnu) and delta Z (epsilonnu) of the aberration coefficient by this inclination eccentricity are expressed with the following formulas (7A) and (7B). In addition, the entrance pupil side PS 1 of ** nu element D[from Point C] nu, the body side OS; distance to the exit pupil side PS 2 corresponding to them and the image surface IS is made into pnu, q nu;p'nu, and q'nu, respectively.
deltaY(epsilonnu) =-[epsilonnu/(2 and alpha'k)] -{(deltaepsilon) nu + N-tanomega2- [(2+cos2phiomega) -(Vepsilon1) nu-(Vepsilon2) nu] + 2andR-(N-tanomega) -[(2 and cos(phi R-phi omega)+cos (phi R+phi omega)) -(IIIepsilon) nu + CosphiR-cosphiomegaand(Pepsilon) nu] + R2-(2+cos2phiR) -(IIepsilon) nu} — (7A) deltaZ(epsilonnu) =-[epsilonnu/(2 and alpha'k)], {(N-tanomega) 2, sin2phiomega, and (Vepsilon1) nu + 2andR-(N-tanomega) - [sin(phi R+phi omega), nu +sinphiR-cosphiomega, and (Pepsilon) nu] +R2andsin2phiR-(IIepsilon) nu} — (7B) [0051] However, an eccentric aberration coefficient is defined by the following formula (7C) - (7H).

(deltaepsilon) nu=-2- (alpha'nu-q'nu-alphanu-qnu) — (7C) (Vepsilon1) nu= {[alpha'nu-q'nu (micro=nu+1->k) and sigmaVmu]-[alpha nu-q nu and (micro=nu->k) sigmaVmu]} - {alpha'#nu-p'nu, [sigmaIIImu]-[alpha#nu-p nu, and (micro=nu->k) sigmaIIImu]} + [(alpha'# nu/N'nu) - (alpha#nu/Nnu)] — (7D) () Vepsilon2nu={[alpha'#nu-p'nu- sigmaPmu]-[alpha#nu-p nu- (Micro=nu+1->k) (Micro=nu->k) sigmaPmu]} + [(alpha'# nu/N'nu) - (alpha#nu/Nnu)] — (7E) (IIIepsilon) nu= {alpha'nu-q'nuand(micro=nu+1->k) [sigmaIIImu]-[alpha nu-q nu and (micro=nu->k) sigmaIIImu]} - {alpha'#nu-p'nu, [sigmaIImu]-[alpha#nu-p nu, and (micro=nu->k) sigmaIImu]} — (7F) nu={[alpha'nu-q'nu- (Pepsilon) sigmaPmu]-[alpha nu-q nu- (Micro=nu+1->k) (Micro=nu->k) sigmaPmu]} + [(alpha'nu/N'nu) - (alphanu/Nnu)] — (7G) (IIepsilon) nu= {alpha'nu-q'nuand(micro=nu+1->k) [sigmaIImu]-[alpha nu-q nu and (micro=nu->k) sigmaIImu]} - {[alpha'# nu-p'nu (micro=nu+1->k) and sigmaImu]-[alpha#nu-p nu and (micro=nu->k) sigmaImu]} — (7H) [0052] Also in inclination eccentricity, the case where sigma is taken as well as the case of parallel eccentricity is considered. When the lens group which carries out eccentricity is made into the j-th page from the i-th page, for example in Pepsilon (Pepsilon) i-j=(nu=i->j) sigma {alpha'nu-q'nu, sigmaPmu-alphanu-qnu, and(micro=nu->k) sigmaPmu}+ [(alpha'nu/N'nu) - (alphanu/Nnu)]} = Alpha'j-q'j, sigmaPmu-alphai-qi, and(micro=i->k) sigmaPmu+(nu=i->j) sigma [(alpha'nu/N'nu) - (alphanu/Nnu)] = Alpha'j-q'j-alphai-qi, sigmaPmu-alphai-qi, and(micro=i->j) sigmaPmu+ [(alpha'j/N'j) - (alphai/nickel)] = alpha'j-q'j-alpha i-qi, (P) R-alpha i-qi, and (P) D+ [(alpha'j/N'j) - (alphai/nickel)] — here — the sum of the aberration coefficient P of (P) R=(micro=j+1->k) sigmaPmu:******, and (P) D=(micro=i->j) sigmaPmu : It is the sum of the aberration coefficient P of an eccentric group, therefore, sigma of an eccentric aberration coefficient can be come out of and expressed as the sum of the aberration coefficient of ******, the sum of the aberration coefficient of an eccentric group, and a constant term.

[0053] When piece dotage aberration of [piece dotage aberration] is performed like the case of parallel eccentricity, it is expressed with the formula (8A) and (8B) showing meridional piece dotage (deltaM") i-j and sagittal piece dotage (deltaS") i-j. Here, eccentricity is set to epsilon.

(deltaM") i-j= [— (8B), however the eccentric aberration coefficient of a block are expressed with the following formulas (8C) and (8D) about meridional one and sagittal each.] - Epsilon-floor line-Y'- [3 and (IIIepsilon) i-j+(Pepsilon) i-j] — (8A) (deltaS") i-j= - Epsilon-floor line-Y'- [(IIIepsilon) i-j+(Pepsilon) i-j]

[3- i-j+ (IIIepsilon) i-j]= (Pepsilon) -[3- (Alpha'j-q'j-alpha i-qi) (III) 3and (II) R+ alpha#i-pi [3and(III) (P) R]-alphai-qi[D+(P) D]-(alpha'# j-p'j-alpha#i-pi) -[R]+] [3and (II) D] + [(alpha'j/N'j) - (alphai/nickel)] — (8C) — [i-j+ (IIIepsilon) (Pepsilon) i-j —] — = (alpha'j-q'j-alpha i-qi) - [(III) — R — + — (— P —) — R —] - alpha — i-qi — [(III) — D — + — (— P —) — D —] - (alpha'# j-p'j-alpha#i-pi) - [— (— II —) — R —] — + — alpha#i-pi — [— (— II —) — D —] — + — [— (alpha'j/N'j) - (alphai/nickel) —] — (8D) [0054] When a [shaft top comatic-aberration] shaft top coma as well as the case of parallel eccentricity is performed, a formula (9A) comes to show it. However, the eccentric aberration coefficient of a block is expressed with a formula (9B).

(AXCM") I-j=epsilon -[(3, kappa2, and floor line3)/(8, FNO2)] and (IIE) i-j — (9A) (IIepsilon) -(II) R-alpha i-qi and (II) D-(alpha'# j-p'j-alpha#i-pi) -(I) R+alpha#i-pi and [i-j=(alpha'j-q'j-alpha i-qi)] (I) D — (9B) [0055] Property>> of the eccentric aberration seen from <<aberration coefficient Although eccentric aberration is expressed with the 3rd aberration coefficient as mentioned above, the relation of the inclination of aberration degradation and aberration coefficient which are known from there is explained below.

[0056] <Eccentric aberration and spec.> Generally eccentric aberration can be expressed with the following formulas (10A) from "derivation of the eccentric aberration by the aberration coefficient" mentioned above.

[Eccentric aberration] = [eccentricity] x[term of spec.] x [an eccentric aberration coefficient] — (10A)

[0057] Therefore, he can understand the sensitivity to eccentric aberration to some extent from spec. so that it may mention to following ** and **.

** Since piece dotage aberration becomes large in proportion to a focal distance and image quantity, it is not avoided with a telephoto lens with a big focal distance. Again. Since the image quantity which evaluates piece dotage aberration by the lens shutter camera and the single-lens reflex camera is different, with the same focal distance, sensitivity [as opposed to eccentric aberration in the direction of a single-lens reflex camera] becomes large.

** Shaft top comatic aberration is proportional to the cube of a focal distance, and in inverse proportion to the square of the f number (FNO), therefore, like a single-lens reflex camera, by the zoom, since shaft top comatic aberration is [the f number] proportional to the cube of a focal distance by the thing of about 1 law, if a focal distance is extended, the sensitivity to eccentric aberration will become large rapidly. Again. Like the zoom lens for lens shutter cameras, the f number becomes large greatly in proportion to a focal distance according to a focal distance. By the latest high scale-factor zoom for lens shutter cameras, since the f number does not change like a focal distance, if it is that a distant view is overlooked, the sensitivity to eccentric aberration will become large suddenly.

[0058] <Property of parallel eccentricity aberration> Generally an parallel eccentricity aberration coefficient can be expressed like the following formulas (11A).

(Eccentric aberration coefficient) i-j=(alpha'j-alphai) -(sum of aberration coefficient 1) R -alphai, and (sum of an aberration coefficient 1) D -(alpha'# j-alpha#i) -(sum of aberration coefficient 2) R + alpha#i, and (sum of an aberration coefficient 2) D — (11A) [0059] In a formula (11A), although the 1st term and the 2nd term are (the sums of an aberration coefficient 2), (the sum of an aberration coefficient 1), the 3rd term, and the 4th term Specifically (in the case of piece dotage aberration) —(aberration coefficient 1) = [astigmatism multiplier (III)] + [the PETTSU bar sum (P)] (aberration coefficient 2) =[comatic-aberration multiplier (II)] (in case of shaft top comatic aberration) —(aberration coefficient 1) = [comatic-aberration multiplier (II)] (aberration coefficient 2) It is = [a spherical-aberration multiplier (I)].

[0060] As mentioned above, the eccentric aberration coefficient {a formula (11A)} consists of the 4th term. Each term is explained below.

The [1st term] — The MAJINARU beam of light on a shaft is however bent by the eccentric group, or the multiplier (alpha'j-alphai) of the 1st term expresses the power of an eccentric group. When an eccentric group is in a body side most especially, it is the power itself, and it is not so so large as - square grade of 10 in order.

The [2nd term] — Multiplier-alphai of the 2nd term is the include angle of axial Uemitsu's MAJINARU beam of light which carries out incidence to an eccentric group. Therefore, a value is not so large. Generally it is so small that an eccentric group is in a body side, and when it is in a body side most especially, it is the description that this term does not contribute at all.

The [3rd term] — Multiplier - (alpha'# j-alpha#i) of the 3rd term is so large that the deflection condition of the chief ray in an eccentric group is expressed and an eccentric group generally separates from a diaphragm. Order is about the 10-1 - 1st power.

The [4th term] — Multiplier alpha#i of the 4th term is the include angle of the chief ray which carries out incidence to an eccentric group, and initial value is -1. A value also seldom changes but is to about -five at most.

[0061] the relation of the magnitude of (an aberration coefficient 1) and a (an aberration coefficient 2) — the direction of (an aberration coefficient 1) — (an aberration coefficient 2) — receiving — 1 - square extent of 10 — it is large. Moreover, as

compared with (an aberration coefficient 1). it is easy to change (an aberration coefficient 2). If the above thing is taken into consideration, the 4th term has a value big general always. Effect becomes large by the location of a diaphragm, or the power of an eccentric group, or other terms become small. Therefore, it is desirable to minimum-ize the 4th term in the usual optical system. However, it may be desirable to minimum-ize other terms according to the configuration of optical system.

[0062] <Property of inclination eccentricity aberration> Generally an inclination eccentricity aberration coefficient can be expressed like the following formulas (12A).

i-j=(alpha'j-q'j-alpha i-qi) -(sum of aberration coefficient 1) R (Eccentric aberration coefficient) - alphai-qi, and (sum of an aberration coefficient 1) D - alpha'#j-p'j-alpha#i-pi, and(sum of an aberration coefficient 2) R + alpha#i-pi, and (sum of an aberration coefficient 2) D + [(alpha'j/N'j) - (alphai/nickel)] (<- -- a constant term -- the case of piece dotage) [-- (12A) -- 0063] Since the entrance pupil location p from the object distance q and the center of rotation C from the center of rotation C is contained in it, an inclination eccentricity aberration coefficient has complicated count as [this]. Then, the center of rotation C is made into the plane peak point of the body side face of an eccentric group, and supposing eccentric group order is air, it can replace as follows.

Alpha'j-q'j=alpha'j-s'j+alpha'j-TD=hj+alpha'j-TD -- (12B) alphai-qi=hi -- (12C) alpha '# j-p'j=h#j+alpha' #j-TD -- (12D) Alpha#i-pi=h#i -- (12E), however hi : Height of the paraxial shaft top MAJINARU beam of light in the i-th page, h#i : the height of the chief ray outside a paraxial shaft in the i-th page, hj : The height of the paraxial shaft top MAJINARU beam of light in the j-th page, h#j : The height of the chief ray outside a paraxial shaft in the j-th page, TD : It is the heart thickness (namely, axial top-face spacing from the i-th page to the j-th page) of an eccentric group.

[0064] If a formula (8C) and the inclination eccentricity aberration coefficient of; (8D) (9B) are expressed once again using upper type (12B) - (12E), it will become like a degree type (12F) and; (12G) (12H).

(Meridional piece dotage aberration) [3 and (IIIepsilon) i-j+(Pepsilon) i-j] =(hj-hi+alpha'j-TD) - [3and(III) R+(P) R] - hi- [3and(III) D+(P) D] - H#j-h#i+alpha'#j-TD- [3and (II) R] + h#i- [3and (II) D] + Alpha'j-alphai -- (12F) (sagittal piece dotage aberration) [(IIIepsilon) i-j+(Pepsilon) i-j] =(hj-hi+alpha'j-TD) - [(III) R+(P) R] - hi- [(III) D+(P) D] -(h#j-h#i+alpha'#j-TD) - [(II) R] +h#i- [(II) D] + Alpha'j-alphai -- (12G) (shaft top comatic aberration) i-j=(hj-hi+alpha'j-TD)and(II)R (IIepsilon) -hi(II) D -(h#j-h#i+alpha'#j-TD) - (I) R +h#iand (I) D -- (12H) [0065] After all, generally an inclination eccentricity aberration coefficient can be expressed like the following formulas (13A). However, eccentric group order is air and it is the case where it inclines focusing on the plane peak point of an eccentric group.

i-j=(hj-hi+alpha'j-TD), and(sum of an aberration coefficient 1) R (Eccentric aberration coefficient) - hi, and (sum of an aberration coefficient 1) D - H#j-h#i+alpha'#j-TD, and(sum of an aberration coefficient 2) R -h#i, and (sum of an aberration coefficient 2) D + (alpha'j-alphai) (<- -- a constant term -- the case of piece dotage) [-- (13A) -- 0066] As mentioned above, the inclination eccentricity aberration coefficient consists of the 4th term in shaft top comatic aberration, and consists of the 5th term in piece dotage aberration. Each term is explained below.

The [1st term] -- Although change is 0.1 to about three in initial value h1=1, since it seldom changes in a group, about 0.1 and the heart thickness TD of hj-hi are five to about 50 in 1-10, and a single-lens reflex camera with a lens shutter camera. Alpha'j is - square grade of 10.

The [2nd term] -- hi is 0.1 to about three.

The [3rd term] -- Since it can be considered about that h#i is the distance from a diaphragm, it is h#j-h#i**TD. Moreover, the initial value of alpha'#j is about the -1 - 1st power of 10 in 1.

The [4th term] -- Since h#i is the distance from a diaphragm about, its change is the largest and it is one to about 50.

The [5th term] -- It is a term only concerning piece dotage aberration, and is the constant term which does not contain the 3rd aberration coefficient. A value is - square grade of 10.

[0067] Moreover, for a spherical-aberration multiplier (I), 1x10-4 and a comatic-aberration multiplier (II) are [50x10-4, an astigmatism multiplier (III), and the PETTSU bar sum (P) of the relation of the magnitude of an aberration coefficient] 500x10-4. If the above thing is taken into consideration, in piece dotage aberration, the 1st term, the 2nd term, and the 5th term have a big value, and depending on the location of a diaphragm, the 4th term can become very large or can be disregarded. That the 5th term especially has a big value means that all aberration coefficients have a value also in 0. Therefore, he can understand the difficulty of making low error sensibility of inclination eccentricity and parallel eccentricity both. Moreover, in shaft top comatic aberration, although the 3rd term and the 4th term become dominant, the 4th term is extracted and changes with locations a lot. As mentioned above, since dominant terms differ with inclination eccentricity and parallel eccentricity, if one aberration coefficient is made small, it turns out that both sensibility does not become small.

[0068] Gestalt>> of the desirable operation drawn from the analysis of <<eccentricity aberration So that derivation of the eccentric aberration mentioned above etc. may show The group which consists of at least one lens side which poses a manufacture top problem since eccentric-error sensibility is relatively large in the optical system of arbitration (it is equivalent to said eccentric group, for example, they are a lens group and a lens side.) It receives, and if the design which makes small the 3rd aberration coefficient used as the key factor which enlarges eccentric-error sensibility is performed, the error sensibility by the eccentricity in the optical system will become small. The optical system concerning this invention, its manufacture approach, and the eccentric-error sensibility reduction design approach are made paying attention to this point, and one of the description of that is in the characteristic design technique which consists of five phases of explaining below.

[0069] The <1st step> Since the 1st step has relatively large eccentric-error sensibility, it is characterized by specifying the group (henceforth "a specific group") which consists of at least one lens side which poses a manufacture top problem (drawing 3 , #10). Specifically, extent of generating of eccentric aberration when eccentricity (it inclines with parallel eccentricity and is eccentricity) actually occurs in each element of the target optical system, a lens block, a lens, and a lens side is investigated with ray tracing. The eccentric aberration which should observe then is the "piece dotage aberration" and the "shaft top comatic aberration" which were mentioned above.

[0070] In recent years, in the field of optical system, the design of a zoom lens is performed actively and many improvement in a zoom ratio and techniques of a miniaturization are announced. However, generally improvement and a miniaturization of a zoom ratio tend to enlarge error sensibility. Although it is necessary to raise manufacture precision if a raise in a scale factor and a miniaturization progress, it has not caught up in the present condition. For this reason, although a scale factor and magnitude are determined from the limitation of manufacture, since a demand of a commercial scene has the large motion which asks for a high scale factor and a small thing, the satisfactory zoom lens is not offered.

[0071] In the case of a zoom lens, in a zoom block, a certain amount of eccentric-error sensibility is becoming absorbable with an alignment technique. However, in the zoom block which moves between zooming, the present condition is being unable to

perform highly precise alignment. The characteristic design technique of this invention is suitable for a zoom lens at this point. When it applies to a zoom lens, it is desirable still more desirable to make a zoom block into a specific group, and it is good that a specific group is biggest zoom group of eccentric-error sensibility.

[0072] The characteristic design technique concerning this invention does not stop in order to reduce the eccentric-error sensibility of only one element of optical system. It can consider as the configuration which has as small eccentric-error sensibility as all the elements of optical system can permit the design technique enough to a manufacture error by repeating and using. Therefore, as for the target element, in zoom optical system with the small eccentric-error sensibility of a zoom block, it is desirable that they are a lens or a lens side. It is because it will become unnecessary to align and will become advantageous on manufacture, if the error sensibility in a zoom block can be reduced.

[0073] When the target optical system is a single focal lens, it is desirable to satisfy the following conditional expression (1).
fL/ymax> 3 --(1) however the focal distance of fL:whole system, ymax: It is screen diagonal length.

[0074] The above-mentioned conditional expression (1) expresses the focal distance of a single focal lens. Error sensibility comes to be conspicuous, so that a focal distance becomes large, so that derivation of the eccentric aberration mentioned above may show. Therefore, at the optical system of a too much short focal distance, since error sensibility is small from the first, there is no need for reduction in many cases.

[0075] The <2nd step> The 2nd step calculates eccentric aberration using the eccentric aberration coefficient of the group (specific group) specified in said 1st step, and is characterized by performing the comparison of the eccentric aberration acquired by the count, actual eccentric aberration (for example, thing obtained with ray tracing), and ** (drawing 3 , #20). An eccentric aberration coefficient is expressed with primary association of each aberration coefficient (3rd aberration coefficient) so that derivation of the eccentric aberration mentioned above may show. In the usual optical system, if the value of the eccentric aberration drawn from the eccentric aberration coefficient is compared with the value of the actual eccentric aberration acquired by ray tracing, it is very well in agreement. He can understand this also from it being well in agreement with aberration with the actual aberration calculated from the 3rd aberration coefficient. However, when many aspheric surfaces are in optical system, the aberration by which high order aberration may occur excessively and is then calculated from the 3rd aberration coefficient, and actual aberration will not be in agreement. Since the eccentric aberration drawn from an eccentric aberration coefficient will naturally differ in a value greatly from actual eccentric aberration, it becomes difficult to perform an analytical design.

[0076] When a design analytical as mentioned above is difficult, it is desirable to design so that magnitude of point distribution in the eccentric condition may be minimum-ized (that is, when it is judged that the eccentric aberration acquired by count differs from actual eccentric aberration greatly) (drawing 3 , #60). Thus, by designing, eccentric aberration can be suppressed small and eccentric-error sensibility can be reduced. The position which carried out eccentricity of the part of eccentric-error sensibility to specifically weaken is actually made, it is made an additional position, in addition to the position of a normal state, the weight of a design is added also to the added eccentric position, and the design which makes the point in an eccentric condition small is performed. If the point became small by enlarging weight of an eccentric condition and the engine performance of a normal state could also be held, eccentric-error sensibility is able to be made small. What is necessary is just to look for the possibility of eccentric-error sensibility reduction by adding suitably the degree of freedom of the aspheric surface, a zoom solution, a lens, etc., when it cannot do.

[0077] The <3rd step> When it is judged that the eccentric aberration acquired by count which used the eccentric aberration coefficient as a result of said comparison in the 2nd step, and the actual eccentric aberration of the step [3rd] acquired by ray tracing correspond well, it is characterized by specifying the 3rd aberration coefficient used as the key factor which enlarges eccentric-error sensibility (drawing 3 , #30). Since the 3rd aberration coefficient dominant in an eccentric aberration coefficient serves as a key factor which enlarges eccentric-error sensibility, it investigates whether the eccentric aberration of a specific group is most influenced of which term of an eccentric aberration coefficient. From the value (or eccentric aberration about each term) of each term of an eccentric aberration coefficient, the term most dominant in an eccentric aberration coefficient is specified. If the term can be specified, specification with which 3rd dominant aberration coefficient can be performed easily. The 3rd aberration coefficient to specify may be one, or may be two or more. It is common that it is the comatic-aberration multiplier (II) of a specific group in the case of piece dotage aberration, and when it is shaft top comatic aberration, as for the 3rd aberration coefficient specified, it is common that it is the spherical aberration (I) of a specific group.

[0078] The <4th step> The 4th step is characterized by performing the design which makes small the 3rd aberration coefficient specified in said 3rd step (drawing 3 , #40). This 4th step is a phase of designing concretely in response to the result of the 3rd-step analysis. When the 3rd aberration coefficient specified in the 3rd step is the 3rd aberration coefficient {()D} of the target element (specific group), even if it is going to make the 3rd aberration coefficient small in the 4th step, the 3rd aberration coefficient with a specific small group cannot be taken. It is desirable to make the 3rd desired aberration coefficient attain by adding a degree of freedom to the target element in that case. Addition of a degree of freedom is addition of the aspheric surface, and addition of a lens.

[0079] When the 3rd aberration coefficient specified in the 3rd step is the 3rd aberration coefficient {()R} of the group (******) which consists of all the lens sides located in an image side from a specific group, even if it is going to make the 3rd aberration coefficient small in the 4th step, the 3rd aberration coefficient with the small ****** cannot be taken. It is desirable in that case to make the 3rd desired aberration coefficient attain by adding a degree of freedom to the image side (namely, ******) of a specific group. Addition of a degree of freedom is addition of the aspheric surface, and addition of a lens.

[0080] The <5th step> The 5th step is characterized by performing the design which prepares the aberration balance changed with the design in the 4th step so that totality ability may be maintained to the same extent as the condition before said design in the 4th step (condition of a dimension) (drawing 3 , #50). Since the 3rd aberration coefficient of a specific element (a specific group and ******) was fluctuated greatly in the 4th step, the 3rd whole aberration coefficient is a big value. Then, it designs so that the 3rd whole aberration coefficient may be made small by making it into a design variable except the element used for the design in the 4th step.

[0081] If aberration fluctuation is too large in the 4th step, it may become difficult to make whole aberration comparable as the original condition. It is desirable to add a degree of freedom to the body side (for example, lens group located in a body side) of a specific group in that case. Addition of a degree of freedom is addition of the aspheric surface, and addition of a lens. Eccentric-error sensibility is not influenced by the aberration coefficient of the lens group located in the body side of the target element (specific group) at all so that clearly from derivation of the eccentric aberration mentioned above etc. Therefore, even if it applies a degree of freedom to the body side of a specific group and fluctuates an aberration coefficient greatly, totality ability can be made equivalent to the original condition without effect at the eccentric-error sensibility of a specific group.

[0082] Difference>> of the eccentric-error sensibility reduction design concerning <<this invention, and the conventional design As stated previously, also conventionally, the design may have been performed about error sensibility and a certain amount of error sensibility reduction was performed. Weakening error sensibility was to enlarge optical system after all by saying that the view makes sensibility small by weakening power of a part with big error sensibility. It is possible to reduce eccentric-error sensibility by according to the characteristic design technique concerning this invention, clarifying existence of a solution with small eccentric-error sensibility, even if it is the same power by analyzing eccentric-error sensibility from an aberration coefficient as mentioned above, and introducing the aspheric surface used in order to raise the engine performance and spec. in the former in order to make the absolute value of an eccentric aberration coefficient small. The image Fig. about the difference between the characteristic design technique concerning this invention for reducing eccentric-error sensibility to drawing 4 and the conventional design technique is shown.
[0083]
[Example] Hereafter, construction data, an aberration Fig., etc. are mentioned and the configuration of the zoom lens which carried out this invention is explained still more concretely. In the construction data of each example and the example of a comparison, ri (i= 1, 2 and 3, ...) is counted from a body side. The radius of curvature of the i-th field, di (i= 1, 2 and 3, ...) is counted from a body side, shows the i-th axial top-face spacing, counts nickel (i= 1, 2 and 3, ...) and nui (i= 1, 2 and 3, ...) from a body side, and shows the refractive index (Nd) and the Abbe number (nud) to d line of the i-th lens. Moreover, axial top-face spacing (variable spacing) which changes in zooming is each shaft top spacing between groups in a wide angle edge (short focal distance edge) [W] middle (middle focal distance condition) [M] - a tele edge (long focal distance edge) [T] among construction data. The focal distance f and the f number FNO of the whole system corresponding to each focal distance condition [W], [M], and [T] are shown collectively.
[0084] It shall be shown that the field where * mark was given to radius of curvature ri is a field which consisted of the aspheric surfaces, and it shall define as the following formula (AS) showing the field configuration of the aspheric surface.
1+(1-epsilon-Y 2, C2) 1 / X= (C, Y2) / {2}+sigma (Ai-Yi) The inside of -- (AS), however a type (AS), and X : the variation rate from the datum level of the direction of an optical axis -- an amount and Y : an optical axis -- receiving -- the height of a perpendicular direction, and C : paraxial curvature, an epsilon:secondary curved-surface parameter, and Ai:i -- it is the following aspheric surface multiplier.
[0085]

《比較例(正・負・正・正)》
f =22.75～60.00～155.40
FNO= 4.60～ 5.22～ 5.80
[曲率半径] [軸上面間隔] [屈折率] [アッベ数]
r1= 80.507
d1= 1.500 N1= 1.83350 ν1= 21.00
r2= 50.638
d2= 0.010 N2= 1.51400 ν2= 42.83
r3= 50.638
d3= 6.300 N3= 1.60311 ν3= 60.74
r4= -590.399
d4= 0.100
r5= 36.741
d5= 4.330 N4= 1.49310 ν4= 83.58
r6= 91.218
d6= 1.300～19.406～33.552
r7*= 91.218
d7= 1.300 N5= 1.76743 ν5= 49.48
r8= 11.256
d8= 4.440
r9= -33.551
d9= 1.000 N6= 1.75450 ν6= 51.57
r10= 45.126
d10= 0.100
r11= 22.081
d11= 2.780 N7= 1.83350 ν7= 21.00
r12= -81.335
d12= 1.290
r13= -26.837
d13= 1.000 N8= 1.75450 ν8= 51.57
r14= 267.900
d14=14.735～7.506～1.200
r15= ∞(絞りA)
d15= 0.720
r16= 19.552
d16= 3.700 N9= 1.51823 ν9= 58.96
r17= -70.651
d17= 0.100
r18= 20.750
d18= 4.000 N10=1.48749 ν10=70.44
r19= -30.525
d19= 1.350
r20= -19.354
d20= 1.000 N11=1.84666 ν11=23.82
r21= 266.334

d21= 4.800～1.900～0.700

r22= 25.488

d22= 4.240 N12=1.51742 ν12=52.15

r23= -18.130

d23= 1.600

r24*= -31.725

d24= 1.400 N13=1.76743 ν13=49.48

r25*= 29.200

d25= 1.250

r26= 30.049

d26= 2.150 N14=1.67339 ν14=29.25

r27= 220.193

[0086] [Page [7th] (r7) aspheric surface data] epsilon= 1.0000 A4=-0.71639468x10-6A6= 0.52909389x10-7A8=-0.15444212x10-8A10= 0.14666388x10-10A12=-0.50346363x10-13[0087] [Page [24th] (r24) aspheric surface data] epsilon= 1.0000 A4=-0.12662318x10-4A6=-0.18371721x10-5A8= 0.64823035x10-7A10=-0.16739676x10-8A12= 0.15325296x10-10[0088] [Page [25th] (r25) aspheric surface data] epsilon= 1.0000 A4= 0.80098384x10-4A6=-0.14551791x10-5A8= 0.54084513x10-7A10=-0.12612528x10-8A12= 0.10743852x10-10[0089]

《実施例1(正・負・正・正)》
f=22.75～60.00～155.47
FNO= 4.60～ 5.22～ 5.80

[曲率半径]	[軸上面間隔]	[屈折率]	[アッベ数]
r1= 67.212			
	d1= 0.850	N1= 1.83350	ν1= 21.00
r2= 46.411			
	d2= 0.010	N2= 1.51400	ν2= 42.83
r3= 46.411			
	d3= 5.611	N3= 1.60311	ν3= 60.74
r4=-1533.625			
	d4= 0.100		
r5= 37.479			
	d5= 3.192	N4= 1.49310	ν4= 83.58
r6= 80.254			
	d6= 1.300～18.806～33.718		
r7*= 55.942			
	d7= 1.885	N5= 1.76743	ν5= 49.48
r8= 11.445			
	d8= 5.063		
r9= -23.786			
	d9= 0.850	N6= 1.75450	ν6= 51.57
r10= 76.080			
	d10= 0.100		
r11= 30.979			
	d11= 2.383	N7= 1.83350	ν7= 21.00
r12= -51.984			
	d12= 3.062		
r13= -14.519			
	d13= 0.850	N8= 1.75450	ν8= 51.57
r14= -33.010			
	d14=15.174～7.640～1.200		
r15= ∞(絞りA)			
	d15= 0.100		
r16= 18.695			
	d16= 3.912	N9= 1.51823	ν9= 58.96
r17= -76.828			
	d17= 0.117		
r18= 17.787			
	d18= 5.364	N10=1.48749	ν10=70.44
r19=-191.752			
	d19= 0.100		
r20=-1380.472			
	d20= 1.305	N11=1.84666	ν11=23.82
r21*= 22.105			

d21= 4.450～0.372～0.700
r22= 13.823
d22= 2.946 N12=1.51742 ν12=52.15
r23= -38.168
d23= 0.100
r24*=203.761
d24= 0.850 N13=1.76743 ν13=49.48
r25*= 15.784
d25= 5.907
r26= 41.896
d26= 1.417 N14=1.67339 ν14=29.25
r27= 183.628

[0090] [Page [7th] (r7) aspheric surface data] epsilon= 1.0000 A4= 0.13382026x10-4A6= 0.98519488x10-7A8=-0.20533289x10-8A10= 0.14078856x10-10A12=-0.28051717x10-13[0091] [Page [21st] (r21) aspheric surface data] epsilon= 1.0000 A4= 0.56033831x10-4A6= 0.20859596x10-6A8=-0.89435819x10-9A10=-0.32902126x10-10A12= 0.14244659x10-11[0092] [Page [24th] (r24) aspheric surface data] epsilon= 1.0000 A4= 0.24244833x10-5A6=-0.18608783x10-5A8= 0.65868793x10-7A10=-0.15356660x10-8A12= 0.15529677x10-10[0093] [Page [25th] (r25) aspheric surface data] epsilon= 1.0000 A4= 0.52954566x10-4A6=-0.15597732x10-5A8= 0.56109687x10-7A10=-0.13012153x10-8A12= 0.13945660x10-10[0094]

《実施例２(正・負・正・正・正)》
f =22.50〜68.20〜215.01
FNO= 4.10〜 5.20〜 5.80
[曲率半径] [軸上面間隔] [屈折率] [アッベ数]
r1= 83.031
d1= 0.900 N1= 1.80518 ν1= 25.43
r2= 58.244
d2= 8.632 N2= 1.49310 ν2= 83.58
r3= -578.162
d3= 0.100
r4= 50.487
d4= 5.067 N3= 1.49310 ν3= 83.58
r5= 130.665
d5= 1.500〜27.727〜47.883
r6= 54.141
d6= 0.900 N4= 1.69100 ν4= 54.75
r7= 13.636
d7= 6.568
r8= -43.963
d8= 0.900 N5= 1.75450 ν5= 51.57
r9= 68.381
d9= 0.100
r10= 22.995
d10= 3.675 N6= 1.75000 ν6= 25.14
r11= -76.156
d11= 1.991
r12= -27.803
d12= 0.900 N7= 1.75450 ν7= 51.57
r13= 76.918
d13=23.778〜12.929〜1.400
r14= ∞(絞りA)
d14= 0.100
r15= 23.349
d15= 2.694 N8= 1.51680 ν8= 64.20
r16=-109.602
d16= 0.100
r17= 17.126
d17= 3.780 N9= 1.48749 ν9= 70.44
r18= 54.839
d18= 2.069
r19=1000.170
d19= 0.960 N10=1.84666 ν10=23.82
r20*= 26.326
d20= 5.000〜0.731〜0.717
r21= 16.450

d21= 3.458 N11=1.51742 ν11=52.15
r22= -41.645
d22= 0.100
r23= 107.729
d23= 1.269 N12=1.80518 ν12=25.43
r24=-234.940
d24= 0.678
r25*=308.495
d25= 0.900 N13=1.85000 ν13=40.04
r26*= 19.631
d26= 1.743
r27= 34.180
d27= 0.900 N14=1.62280 ν14=56.88
r28= 28.353
d28= 2.500～15.493～13.880
r29= 27.227
d29= 1.641 N15=1.85000 ν15=40.04
r30= 36.334

[0095] [Page [20th] (r20) aspheric surface data] epsilon= 1.0000 A4= 0.29375182x10-4A6=-0.61263568x10-7A8= 0.72651555x10-9A10= 0.14884299x10-10A12=-0.22214701x10-12[0096] [Page [25th] (r25) aspheric surface data] epsilon= 1.0000 A4= 0.59719107x10-5A6=-0.15750654x10-6A8=-0.76280738x10-8A10=-0.18941169x10-10A12= 0.12179777x10-11A14= 0.19818816x10-13A16=-0.35165979x10-15[0097] [Page [26th] (r26) aspheric surface data] epsilon= 1.0000 A4= 0.53641668x10-4A6= 0.64473049x10-6A8=-0.19461151x10-7A10=-0.42546389x10-10A12= 0.38972037x10-11A14= 0.38043446x10-13A16=-0.94934519x10-15[0098]

《実施例3（正・負・正・正）》
f =22.75～60.00～155.40
FNO= 4.60～ 5.22～ 5.80

[曲率半径]	[軸上面間隔]	[屈折率]	[アッベ数]
r1= 73.644			
	d1= 0.850	N1= 1.83350	ν1= 21.00
r2= 49.348			
	d2= 0.010	N2= 1.51400	ν2= 42.83
r3= 49.348			
	d3= 6.787	N3= 1.60311	ν3= 60.74
r4= -712.296			
	d4= 0.100		
r5= 35.459			
	d5= 3.967	N4= 1.49310	ν4= 83.58
r6= 74.524			
	d6= 1.300～20.632～33.920		
r7*= 46.570			
	d7= 0.850	N5= 1.76743	ν5= 49.48
r8= 10.755			
	d8= 4.530		
r9= -27.774			
	d9= 0.850	N6= 1.75450	ν6= 51.57
r10= 46.989			
	d10= 0.100		
r11= 24.010			
	d11= 2.281	N7= 1.83350	ν7= 21.00
r12= -90.639			
	d12= 2.743		
r13= -17.051			
	d13= 0.850	N8= 1.75450	ν8= 51.57
r14= -43.623			
	d14=15.155～7.948～1.200		
r15= ∞(絞りA)			
	d15= 0.100		
r16= 21.240			
	d16= 3.209	N9= 1.51823	ν9= 58.96
r17= -44.629			
	d17= 0.891		
r18= 23.330			
	d18= 4.839	N10=1.48749	ν10=70.44
r19= -36.872			
	d19= 1.199		
r20= -20.796			
	d20= 0.850	N11=1.84666	ν11=23.82
r21*=270.860			

d21= 4.193~0.937~0.700
r22= 23.066
d22= 3.862 N12=1.51742 ν12=52.15
r23= -18.159
d23= 1.524
r24*=-35.189
d24= 0.850 N13=1.76743 ν13=49.48
r25*= 26.402
d25= 3.487
r26= 48.817
d26= 1.623 N14=1.67339 ν14=29.25
r27=-167.772

[0099] [Page [7th] (r7) aspheric surface data] epsilon= 1.0000 A4= 0.44355027x10-5A6= 0.37073814x10-7A8=-0.14298960x10-8A10= 0.13373838x10-10A12=-0.41256179x10-13[0100] [Page [21st] (r21) aspheric surface data] epsilon= 1.0000 A4= 0.10880422x10-4A6= 0.87297423x10-7A8=-0.46204110x10-9A10=-0.16402917x10-10A12= 0.30793032x10-12[0101] [Page [24th] (r24) aspheric surface data] epsilon= 1.0000 A4=-0.69215309x10-5A6=-0.18251333x10-5A8= 0.65109565x10-7A10=-0.16403658x10-8A12= 0.15287778x10-10[0102] [Page [25th] (r25) aspheric surface data] epsilon= 1.0000 A4= 0.69987925x10-4A6=-0.15500116x10-5A8= 0.53872257x10-7A10=-0.12642621x10-8A12= 0.11335431x10-10[0103] Drawing 5 - drawing 7 are the lens block diagrams corresponding to the zoom lens of the above-mentioned example 1 - an example 3, respectively, and show lens arrangement in a wide angle edge [W]. The arrow heads m1-m5 in each lens block diagram show typically migration of the 1st group Gr1 in zooming from a wide angle edge [W] to a tele edge [T] - the 5th group Gr5, respectively. Moreover, among each lens block diagram, the field where ri (i= 1, 2 and 3, ...) was attached is counted from a body side, and is the i-th field (the field where * mark was given to ri is the aspheric surface). Each axial top-face spacing between groups to which di (i= 1, 2 and 3, ...) was given is variable spacing which counts from a body side and changes in zooming among the i-th axial top-face spacing.
[0104] Drawing 8 - drawing 10 are the aberration Figs. corresponding to an example 1 - an example 3, respectively, and [W] shows many aberration [in / a wide angle edge and [M], and / in [T] / a tele edge] (to the order from the left, they are astigmatism, such as spherical aberration, and distortion;Y':image quantity) among each drawing. [middle] Moreover, among each aberration Fig., sine condition is expressed and, as for the continuous line (d), the broken line (DM) and the continuous line (DS) express the astigmatism over d line in a meridional side and a sagittal side, respectively, as for the aberration and the broken line (SC) to d line.
[0105] Eccentric-error sensibility reduction design>> from the example of <<comparison to an example 1 As stated previously, when eccentricity occurs within a zoom group, with the latest technique, it is possible by aligning by the zoom block to suppress generating of eccentric aberration. However, when a zoom block inclines or parallel eccentricity is started, it is difficult to stop the eccentricity of the zoom block which is a movable group. then, the example in the case of performing said eccentric-error sensibility reduction design to a zoom lens (example of a comparison) -- mentioning -- the 1- the 5th-step concrete configuration is explained. in addition, the 4th group Gr4 in which the example of a comparison (condition before performing an eccentric-error sensibility reduction design) has forward power with the 1st group Gr1 which has forward power sequentially from a body side, the 2nd group Gr2 which has negative power, and the 3rd group Gr3 which has forward power -- since -- it is the zoom lens of 4 group configurations which change and perform zooming by spacing change of each group.
[0106] The <1st step> First, ray tracing investigated the eccentric-error sensibility of each zoom block of the example of a comparison, and since eccentric-error sensibility was relatively large, the zoom group which poses a manufacture top problem was specified (drawing 3 , #10). The eccentric aberration (if it puts in another way eccentric-error sensibility) in a tele edge [T] when each zoom group of the example of a comparison starts 0.1mm parallel eccentricity is shown in Table 1. DM and DS express meridional one and sagittal piece dotage aberration among Table 1, AXCM expresses shaft top comatic aberration, respectively, and piece dotage aberration shows the value of image quantity Y'=-14.4. Table 1 shows that the eccentric-error sensibility of the 3rd group Gr3 and the 4th group Gr4 is very large. Then, the 4th group Gr4 was specified as a group (zoom block) which makes eccentric-error sensibility small.
[0107]
[Table 1]
《比較例の望遠端[T]での各ズームブロックの偏心収差(mm)》

平行偏心：[偏心量]＝0.1mm

	DM	DS	AXCM
第1群	0.110	0.051	0.002
第2群	-0.063	0.076	-0.001
第3群	1.280	0.284	0.030
第4群	-1.217	-0.393	-0.031

[0108] The <2nd step> Next, the eccentric-error sensibility (eccentric aberration) of the 4th group Gr4 which is a specific group of the example of a comparison was calculated from the eccentric aberration coefficient (drawing 3 , #20). The 3rd aberration coefficient of the 4th group Gr4 and its ****** is shown in Table 2. Sequentially from the left, they are a spherical-aberration

multiplier (I), a comatic-aberration multiplier (II), an astigmatism multiplier (III), the PETTSU bar sum (P), and a distortion aberration coefficient (V). Since the 4th group Gr4 is a zoom group by the side of an image most, it does not have the ******. Therefore, all of the 3rd aberration coefficient of ****** are 0. [Eccentricity (0.1mm)] x [the term of spec.], [the multiplier of primary association] about each term, and the count result of [eccentric aberration] are shown in Table 3. Although an eccentric aberration coefficient is expressed with primary association with the 3rd aberration coefficient of a specific group, and the 3rd aberration coefficient of ******, the multiplier of the primary association is [a multiplier of primary association] of the right column of each term. Moreover, the 1st term in Table 3 - the 4th term are equivalent to the 1st term of [an eccentric aberration coefficient] - the 4th term, and are [eccentric aberration] with the final sum total. The comparison with this total value and actual eccentric aberration (Table 1) was performed (drawing 3 , #20).
[0109]
[Table 2]
《比較例の特定群(第4群)と像側群の3次収差係数》

	(I)	(II)	(III)	(P)	(V)
特定群( )D	-8.5792×10^{-6}	-7.8172×10^{-4}	-3.284×10^{-2}	1.5194×10^{-2}	-0.7879×10^{-0}
像側群( )R	0	0	0	0	0

[0110]
[Table 3]
《比較例の望遠端[T]での第4群の平行偏心による偏心収差(mm)》

	DM	DS	AXCM		
	-E・FL・Y'	-E・FL・Y'	E・[(3・κ²・FL³)/(8・FNO²)]		
	223.776	223.776	2049.861		
第1項	0.000	0.000	0.000	(α'j-αi)	0.010
第2項	0.058	0.012	0.005	-αi	0.003
第3項	0.000	0.000	0.000	-(α'♯j-α♯i)	-0.249
第4項	-1.161	-0.387	-0.039	α♯i	-2.213
合計	-1.103	-0.375	-0.034		
実際	-1.217	-0.393	-0.031		

[0111] The <3rd step> When two values were compared, it turned out that the value acquired by count using an eccentric aberration coefficient and the value acquired by actual ray tracing are very well in agreement. Therefore, eccentric aberration can be controlled with the 3rd aberration coefficient. What is necessary is just to perform the design which minimum-izes the point in an eccentric condition in that case, since actual aberration may not become small even if it controls with the 3rd aberration coefficient, when two values have shifted greatly (drawing 3 , #60).
[0112] As shown in Table 3, it is the thing of the sum total of shaft top comatic aberration (AXCM) which all almost depend on the value of the 4th term. The 4th term of the eccentric aberration coefficient of shaft top comatic aberration is referring to [which requires [the multiplier of primary association] for the spherical-aberration multiplier (I) D of an eccentric group (specific group)] the {type (6F). }. It is referring to [[whose multiplier of primary association] piece dotage aberration also has the 4th dominant term, and the 4th term of the eccentric aberration coefficient of piece dotage aberration requires for the comatic-aberration multiplier (II) D of an eccentric group (specific group)] the {type (5G). }. Therefore, that what is necessary is just to make small the spherical-aberration multiplier (I) D of the 4th group Gr4 in order to make small shaft top comatic aberration by the parallel eccentricity of the 4th group Gr4, in order to have made small piece dotage aberration by parallel eccentricity, it turned out that what is necessary is just to make small the comatic-aberration multiplier (II) D of the 4th group Gr4 (drawing 3 , #30).
[0113] The <4th step> Since the 3rd aberration coefficient used as the key factor which enlarges eccentric-error sensibility was specified in the 3rd above-mentioned step, the design which makes these small is performed (drawing 3 , #40). Specifically, the spherical-aberration multiplier (I) D and the comatic-aberration multiplier (II) D of the 4th group Gr4 are made small. The 3rd aberration coefficient when performing the design which makes small the 3rd aberration coefficient (I) D and (II) D, eccentric aberration, etc. are similarly shown with Table 2 and Table 3 in Table 4 and Table 5. as shown in Table 5, shaft top comatic aberration and piece dotage aberration are markedly alike compared with both the examples of a comparison, and small because the spherical-aberration multiplier (I) D and the comatic-aberration multiplier (II) D of the 4th group Gr4 become small.
[0114]
[Table 4]

《比較例の３次収差係数(I)D,(II)Dを小さくした場合》

	(I)	(II)	(III)	(P)	(V)
特定群( )D	-1.4195 $\times 10^{-6}$	-1.6263 $\times 10^{-4}$	0.264 $\times 10^{-2}$	1.5638 $\times 10^{-2}$	1.8596 $\times 10^{-0}$
像側群( )R	0	0	0	0	0

[0115]
[Table 5]
《比較例の３次収差係数(I)D,(II)Dを小さくした場合》

	DM	DS	AXCM		
	-E・FL・Y'	-E・FL・Y'	E・[(3・κ²・FL³)/(8・FNO²)]		
	223.865	223.865	2052.295		
第１項	0.000	0.000	0.000	(α'j-αi)	0.010
第２項	-0.016	-0.012	0.001	-αi	0.003
第３項	0.000	0.000	0.000	-(α'#j-α#i)	-0.348
第４項	-0.247	-0.082	-0.007	α#i	-2.263
合計	-0.263	-0.095	-0.006		

[0116] The <5th step> If only the 3rd aberration coefficient of the 4th group Gr4 is changed as mentioned above, since the balance of the 3rd whole aberration coefficient will collapse, even if eccentric-error sensibility becomes small, the problem that satisfactory optical-character ability cannot be obtained produces it. Then, the 3rd aberration coefficient of the 4th changed group Gr4 was left as it was, and it designed so that the sum of the 3rd whole aberration coefficient might become small (drawing 3 , #50). In order to change sharply the 3rd aberration coefficient of the 3rd group Gr3, the aspheric surface was added to the 3rd group Gr3, and specifically, it designed so that satisfactory optical-character ability might be obtained in all zoom fields. Since effect did not attain to the eccentric aberration of the 4th group Gr4 even if it changed the 3rd aberration coefficient of the 1st group Gr1 - the 3rd group Gr3, satisfactory optical-character ability and eccentric-error sensibility reduction of the 4th group Gr4 were able to be attained to coincidence.
[0117] The condition after the design which added the above-mentioned aspheric surface is the above-mentioned example 1. The actual eccentric aberration after the design is similarly shown with Table 1 in Table 6. As shown in Table 6, the eccentric-error sensibility of the 3rd group Gr3 is also small with eccentric-error sensibility reduction of the 4th group Gr4 whose intention it had. The sum of the 3rd aberration coefficient in the tele edge [T] of each zoom group of the example of a comparison and an example 1 is shown in Table 7. The description is looked at by the point that the 3rd aberration coefficient of the 3rd group Gr3 and the 4th group Gr4 is small after the design mentioned above although both the magnitude of the 3rd whole aberration coefficient is small.
[0118]
[Table 6]
《実施例１の望遠端[T]での各ズームブロックの偏心収差(mm)》

平行偏心：[偏心量]＝0.1mm

	DM	DS	AXCM
第１群	0.105	0.052	0.002
第２群	0.018	0.097	0.000
第３群	0.175	-0.049	0.005
第４群	-0.291	-0.101	-0.007

[0119]
[Table 7]

《比較例と実施例１の望遠端［Ｔ］での各ズーム群の３次収差係数の和》

収差係数		(I) ×10^-6	(II) ×10^-4	(III) ×10^-2	(P) ×10^-2	(V) ×10^-0
比較例	第１群	1.1613	-1.8144	4.3567	1.0104	-12.7781
	第２群	-3.528	-0.6739	-6.1886	-4.7615	8.722
	第３群	11.057	10.307	5.111	2.341	-0.619
	第４群	-8.579	-7.817	-3.284	1.519	-0.788
	合計	0.111	0.002	-0.005	0.109	-5.463
実施例1	第１群	1.0889	-1.7327	4.2753	1.0017	-13.1635
	第２群	-1.5283	0.9903	-5.3468	-4.7081	8.8763
	第３群	1.829	2.783	0.749	2.176	-2.816
	第４群	-1.420	-1.626	0.264	1.564	1.860
	合計	-0.030	0.414	-0.061	0.034	-5.244

[0120]
[Effect of the Invention] According to the optical system of this invention, as explained above, said 3rd aberration coefficient to which eccentric-error sensibility enlarges eccentric-error sensibility to a specific large group relatively is made small, since it has the composition of having prepared aberration balance further, irrespective of whether a specific group includes the aspheric surface etc., the error sensibility of the eccentric aberration of a specific group is reduced, and good optical-character ability is attained. Moreover, according to the manufacture approach of this invention, and the eccentric-error sensibility reduction design approach, the eccentric aberration generated with a manufacture error can be suppressed small, and the optical system which has good optical-character ability can be acquired.

[Translation done.]

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] Drawing for explaining the relation and the aberration coefficient of optical system and a coordinate.
[Drawing 2] Drawing for explaining derivation of an eccentric aberration coefficient.
[Drawing 3] The flow chart which shows the procedure of the eccentric-error sensibility reduction design concerning this invention.
[Drawing 4] The image Fig. for explaining the difference between the eccentric-error sensibility reduction design concerning this invention, and the conventional design.
[Drawing 5] The lens block diagram of an example 1.
[Drawing 6] The lens block diagram of an example 2.
[Drawing 7] The lens block diagram of an example 3.
[Drawing 8] The aberration Fig. of an example 1.
[Drawing 9] The aberration Fig. of an example 2.
[Drawing 10] The aberration Fig. of an example 3.
[Description of Notations]
Gr1 -- The 1st group
Gr2 -- The 2nd group
Gr3 -- The 3rd group
Gr4 -- The 4th group
Gr5 -- The 5th group
A -- Diaphragm

[Translation done.]

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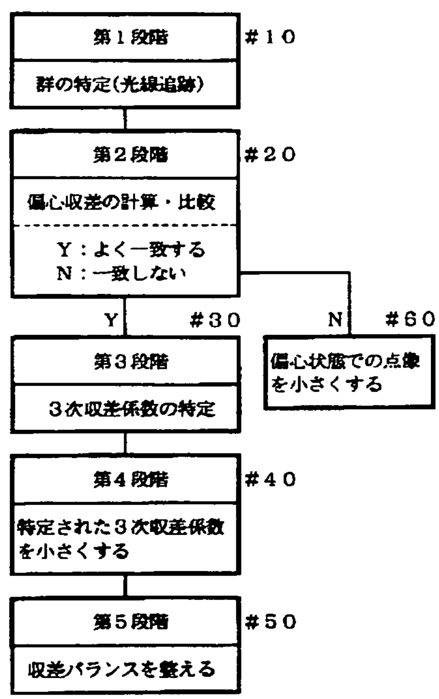
(54)【発明の名称】　光学系，その製造方法及び偏心誤差感度低減設計方法

(57)【要約】

【課題】　製造誤差で発生する偏心収差を小さく抑えて、良好な光学性能を有する光学系，その製造方法及び偏心誤差感度低減設計方法を提供する。

【解決手段】　任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる群を特定する第１段階，特定された群の偏心収差係数を用いて偏心収差を計算し、得られた偏心収差と光線追跡により得られた実際の偏心収差との比較を行う第２段階，偏心収差がよく一致すると判断した場合、偏心誤差感度を大きくする主要因の３次収差係数を特定する第３段階，３次収差係数を小さくする第４段階，全体性能が設計前状態と同程度に維持されるように収差バランスを整える第５段階，を有する。



【特許請求の範囲】

【請求項１】　任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、
該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、
該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、
該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、
全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、
によって設計された光学系。

【請求項２】　請求項１記載の光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大きなズーム群であることを特徴とする光学系。

【請求項３】　前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計して成る請求項１記載の光学系。

【請求項４】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする請求項１記載の光学系。

【請求項５】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする請求項１記載の光学系。

【請求項６】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする請求項１記載の光学系。

【請求項７】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする請求項１記載の光学系。

【請求項８】　前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする請求項１記載の光学系。

【請求項９】　任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、
該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、
該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、
該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、
全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、
を有することを特徴とする光学系の製造方法。

【請求項１０】　前記光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大きなズーム群であることを特徴とする請求項９記載の光学系の製造方法。

【請求項１１】　前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計を行うことを特徴とする請求項９記載の光学系の製造方法。

【請求項１２】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする請求項９記載の光学系の製造方法。

【請求項１３】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする請求項９記載の光学系の製造方法。

【請求項１４】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする請求項９記載の光学系の製造方法。

【請求項１５】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする請求項９記載の光学系の製造方法。

【請求項１６】　前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする請求項９記載の光学系の製造方法。

【請求項１７】　任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、
該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、
該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、
該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、
全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、
を有することを特徴とする偏心誤差感度低減設計方法。

【請求項１８】　前記光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大き

なズーム群であることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項１９】　前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計を行うことを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項２０】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項２１】　前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項２２】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項２３】　前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【請求項２４】　前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする請求項１７記載の偏心誤差感度低減設計方法。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、光学系，その製造方法及び偏心誤差感度低減設計方法に関するものであり、更に詳しくは、あらゆる光学系（例えばカメラの撮影光学系）に対して適用可能な特長を備えた、偏心誤差感度の小さい光学系，その製造方法及び偏心誤差感度低減設計方法に関するものである。

【０００２】

【従来の技術】例えば光学系の製造において、光学系の一部に平行偏心や傾き偏心等の偏心誤差が生じると、偏心収差が発生する。この偏心収差の誤差感度は、光学系の製造を困難にする一つの要因となる。従来、偏心誤差感度の小さな光学系で一般的なものは、問題となるレンズ群のパワーを小さくすることによって、パワー比の分の誤差感度を低減するものである。また、特開平８－２２０４３５号公報では、非球面の偏心に対する感度を低減させるため、両非球面レンズの互いのレンズ面の相対的な偏心により発生する像面傾斜が所定値以下となるように、非球面の基準曲率半径とデビエーションとの大小関係を規定したズームレンズが提案されている。

【０００３】

【発明が解決しようとする課題】前者の光学系では、パワーを大幅に変えることをしない限り、偏心誤差感度を大幅に低減することができない。一方、後者のズームレンズでは、両非球面レンズの互いのレンズ面の相対的な偏心のみが規定されているが、誤差感度は非球面であれば常に大きいわけではない。例えば、非球面であっても曲率半径が大きくデビエーションの小さい面であれば、偏心に対する誤差感度は小さく、逆に、球面であっても曲率半径の小さい面であれば偏心に対する誤差感度は大きい。したがって、両非球面レンズの偏心に対する誤差感度のみを低減させても、光学系全体の偏心に対する誤差感度を低減することができるわけではない。

【０００４】本発明は、これらの点に鑑みてなされたものであって、偏心によって生じる偏心収差を解析することで偏心収差の成り立ちを明らかにし、製造誤差で発生する偏心収差を小さく抑えて、良好な光学性能を有する光学系，その製造方法及び偏心誤差感度低減設計方法を提供することを目的とする。

【０００５】

【課題を解決するための手段】上記目的を達成するために、第１の発明の光学系は、任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、によって設計された構成となっている。

【０００６】第２の発明の光学系は、上記第１の発明の構成において、その光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大きなズーム群であることを特徴とする。

【０００７】第３の発明の光学系は、上記第１の発明の構成において、前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計した構成となっている。

【０００８】第４の発明の光学系は、上記第１の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする。

【０００９】第５の発明の光学系は、上記第１の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする。

【００１０】第６の発明の光学系は、上記第１の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする。
【００１１】第７の発明の光学系は、上記第１の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする。
【００１２】第８の発明の光学系は、上記第１の発明の構成において、前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする。
【００１３】第９の発明の光学系の製造方法は、任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、を有することを特徴とする。
【００１４】第１０の発明の光学系の製造方法は、上記第９の発明の構成において、前記光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大きなズーム群であることを特徴とする。
【００１５】第１１の発明の光学系の製造方法は、上記第９の発明の構成において、前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計を行うことを特徴とする。
【００１６】第１２の発明の光学系の製造方法は、上記第９の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする。
【００１７】第１３の発明の光学系の製造方法は、上記第９の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする。
【００１８】第１４の発明の光学系の製造方法は、上記第９の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする。
【００１９】第１５の発明の光学系の製造方法は、上記第９の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする。
【００２０】第１６の発明の光学系の製造方法は、上記第９の発明の構成において、前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする。
【００２１】第１７の発明の偏心誤差感度低減設計方法は、任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも１つのレンズ面から成る群を特定する第１段階と、該第１段階で特定された群の偏心収差係数を用いて偏心収差を計算し、該計算によって得られた偏心収差と実際の偏心収差との比較を行う第２段階と、該第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とがよく一致すると判断した場合、前記偏心誤差感度を大きくする主要因となっている３次収差係数を特定する第３段階と、該第３段階で特定された３次収差係数を小さくする設計を行う第４段階と、全体性能が前記第４段階での設計の前の状態と同程度に維持されるように、前記第４段階での設計に伴って変動した収差バランスを整える設計を行う第５段階と、を有することを特徴とする。
【００２２】第１８の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記光学系がズームレンズであって、前記第１段階で特定される群が偏心誤差感度の最も大きなズーム群であることを特徴とする。
【００２３】第１９の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記第２段階での比較の結果、前記計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合、偏心状態での点像分布の大きさを極小化するように設計を行うことを特徴とする。
【００２４】第２０の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側へのレンズの追加であることを特徴とする。
【００２５】第２１の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記第４段階での設計が、前記第１段階で特定された群又はその群よりも像側への非球面の付加であることを特徴とする。
【００２６】第２２の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側へのレンズの追加であることを特徴とする。
【００２７】第２３の発明の偏心誤差感度低減設計方法は、上記第１７の発明の構成において、前記第５段階での設計が、前記第１段階で特定された群よりも物体側への非球面の付加であることを特徴とする。
【００２８】第２４の発明の偏心誤差感度低減設計方法

は、上記第１７の発明の構成において、前記第４段階及び第５段階での設計が、全系のパワー配置を変化させずに行われることを特徴とする。

【００２９】

【発明の実施の形態】以下、本発明を実施した光学系，その製造方法及び偏心誤差感度低減設計方法を、図面を参照しつつ説明する。まず、収差係数による偏心収差の導出と収差係数から見た偏心収差の特性を説明する。

【００３０】《収差係数による偏心収差の導出》光学系の一部(例えば、面，レンズ，レンズ群)が、光軸に対して垂直方向に位置ズレを起こしたり傾いたりすると(すなわち平行偏心や傾き偏心等の偏心誤差が発生した場合)、その偏心によって光学性能が劣化する。これは、偏心によって光学系に偏心収差が発生するからである。この偏心収差の誤差感度は、光学系の製造を困難にする一つの要因となる。偏心収差で主なものは、片ボケ収差と軸上コマ収差である。

【００３１】「片ボケ収差」とは、像面が光軸について非対称になる現象である。つまり、偏心が発生することによって、正の画角と負の画角とで像面位置が異なってしまう現象である。片ボケ収差は、通常、画面対角の７割程度の画角の主光線の近軸像面位置での差の平均値で評価される。一方、「軸上コマ収差」とは、軸上光束が主光線に関して非対称になる現象である。回転対称であるべき光学系によれば、軸上の点像も通常回転対称となる。しかし、光学系の一部に偏心が発生すると、対称性が崩れて像性能が大きく劣化してしまうのである。軸上コマ収差は、通常、軸上有効径の７割程度の径の軸上の上側ゾーナル光線(Upper)と下側ゾーナル光線(Lower)の光線位置平均と軸上主光線位置との差で評価される。以下に、偏心の存在する光学系の収差を検討し、収差係数を用いて上記２つの偏心収差を導出する。

【００３２】〈偏心の存在する光学系の３次の収差展開式〉図１に、基本となる光学系と座標との関係を示す。図１(Ａ)，(Ｂ)において、OSは物体平面、ISは像平面、PS1は入射瞳面、PS2は射出瞳面、HS1は物体側主平面(H:物体側主点)、HS2は像側主平面(H':像側主点)、SFは光学系の前面、SRは光学系の後面、Nは物体空間における屈折率、N'は像空間における屈折率である。

【００３３】偏心が存在しないときの光学系の光軸を基準軸AXとしてこれをX軸とし、これに垂直にY軸，Z軸をとる。そして、物点OPの座標を(Y,Z)、入射瞳面PS1上の光線の入射点の座標を(Y*,Z*)とし、これらに対応する像空間の座標には「'」を付けて表す。ただし、像平面IS上の光線の横収差を３次のベキ級数に展開するに当たっては、物点OPと入射瞳面PS1上の光線の入射点の座標として、次の極座標を用いて定義する。

$\tan\omega\cdot\cos\phi\omega\equiv Y/g\$$ …(1A)

$\tan\omega\cdot\sin\phi\omega\equiv Z/g\$$ …(1B)

$R\cdot\cos\phi R\equiv(g\$/g)\cdot Y*$ …(2A)

$R\cdot\sin\phi R\equiv(g\$/g)\cdot Z*$ …(2B)

【００３４】図１から分かるように、g，g$はそれぞれ入射瞳面PS1，物体側主平面HS1から物体平面OSまでの距離、ωは物点OPと物体側主点Hとを結ぶ直線が基準軸AXとなす角で、φωがそのアジムス角(azimuth)、また、Rは物体側主平面HS1上に換算した入射瞳半径でφRがそのアジムス角である。「'」は像空間を表し、「#」は軸外主光線を表すので、αは近軸軸上マージナル光線の物体空間における換算傾角、α#は近軸軸外主光線の物体空間における換算傾角、α'は近軸軸上マージナル光線の像空間における換算傾角、α'#は近軸軸外主光線の像空間における換算傾角である。

【００３５】光学系がk個のエレメントから成り立っているとして、偏心が存在するときの横収差をベキ級数に展開すると、横収差ΔY'，ΔZ'は以下の式(3A)，(3B)に示す形になる(β:横倍率)。球面収差，コマ収差，非点収差，ペッツバール和及び歪曲収差にそれぞれ対応する３次の収差係数はI，II，III，P及びVであり、指数μはエレメント番号であり、α'=α'k，α'#=α'#kである。なお、総和記号Σを用いた表示は、以下の例に示すように行うものとする(以下同様。)。

【００３６】

【外１】

$$\sum_{\mu=1}^{k} \quad : \quad (\mu=1\rightarrow k)\Sigma$$

【００３７】

$$\begin{aligned}
\Delta Y' &\equiv Y'-\beta\cdot Y\\
&=-[1/(2\cdot\alpha')]\cdot\{(N\cdot\tan\omega)^3\cdot\cos\phi\omega\cdot(\mu=1\rightarrow k)\Sigma V\mu\\
&\quad +R\cdot(N\cdot\tan\omega)^2\cdot[2\cdot\cos(\phi R-\phi\omega)\cdot\cos\phi\omega\cdot(\mu=1\rightarrow k)\Sigma III\mu\\
&\qquad +\cos\phi R\cdot(\mu=1\rightarrow k)\Sigma(III\mu+P\mu)]\\
&\quad +R^2\cdot(N\cdot\tan\omega)\cdot[2\cdot\cos\phi R\cdot\cos(\phi R-\phi\omega)+\cos\phi\omega]\cdot(\mu=1\rightarrow k)\Sigma II\mu\\
&\quad +R^3\cdot\cos\phi R\cdot(\mu=1\rightarrow k)\Sigma I\mu\}\\
&\quad +\{\text{偏心による付加項(Y成分)}\} \quad \cdots(3A)
\end{aligned}$$

$$\begin{aligned}
\Delta Z' &\equiv Z'-\beta\cdot Z\\
&=-[1/(2\cdot\alpha')]\cdot\{(N\cdot\tan\omega)^3\cdot\sin\phi\omega\cdot(\mu=1\rightarrow k)\Sigma V\mu\\
&\quad +R\cdot(N\cdot\tan\omega)^2\cdot[2\cdot\cos(\phi R-\phi\omega)\cdot\sin\phi\omega\cdot(\mu=1\rightarrow k)\Sigma III\mu\\
&\qquad +\sin\phi R\cdot(\mu=1\rightarrow k)\Sigma(III\mu+P\mu)]
\end{aligned}$$

$$+R^2\cdot(N\cdot\tan\omega)\cdot[2\cdot\sin\phi R\cdot\cos(\phi R-\phi\omega)+\sin\phi\omega]\cdot(\mu=1\to k)\,\Sigma\,\mathrm{II}\mu$$
$$+R^3\cdot\sin\phi R\cdot(\mu=1\to k)\,\Sigma\,\mathrm{I}\mu\}$$
$$+\{\text{偏心による付加項(Z成分)}\}\quad\cdots(3B)$$

【0038】これらの式（3A），（3B）において、右辺の最初の｛｝内は偏心の存在しないときの光学系本来の収差を表す項であり、偏心が存在すると、偏心によって発生した収差項がそれに加わる形になる。光学系中の任意のエレメント（単一面であっても複数面から成る複合系であってもよい。）が偏心する場合、その偏心には、光学系の基準軸AXに対して垂直な方向に平行移動する「平行偏心」と、基準軸AXに対して傾く「傾き偏心」と、がある。それらの影響は、いずれも上記式(3A)，(3B)の右辺最後の付加項として表される。

【0039】〈平行偏心収差係数の導出〉図2(A)は、光学系中の任意のν番目のエレメント（以下「第νエレメント」といい、第νエレメントの光軸をAXνで表す。）Dνが、光学系の基準軸AXに対して垂直なY方向に、微小量Eνだけ平行偏心した状態を示している。この平行偏心による収差係数の付加項ΔY(Eν)，ΔZ(Eν)は、以下の式(4A)，(4B)で表される。

$$
\begin{aligned}
\Delta Y(E\nu)=&-[E\nu/(2\cdot\alpha'k)]\cdot\{(\Delta E)\nu\\
&+(N\cdot\tan\omega)^2\cdot[(2+\cos2\phi\omega)\cdot(\mathrm{VE1})\nu-(\mathrm{VE2})\nu]\\
&+2\cdot R\cdot(N\cdot\tan\omega)\cdot[(2\cdot\cos(\phi R-\phi\omega)+\cos(\phi R+\phi\omega))\cdot(\mathrm{IIIE})\nu\\
&\quad+\cos\phi R\cdot\cos\phi\omega\cdot(\mathrm{PE})\nu]\\
&+R^2\cdot(2+\cos2\phi R)\cdot(\mathrm{IIE})\nu\}\quad\cdots(4A)
\end{aligned}
$$

$$
\begin{aligned}
\Delta Z(E\nu)=&-[E\nu/(2\cdot\alpha'k)]\cdot\{(N\cdot\tan\omega)^2\cdot\sin2\phi\omega\cdot(\mathrm{VE1})\nu\\
&+2\cdot R\cdot(N\cdot\tan\omega)\cdot[\sin(\phi R+\phi\omega)\cdot(\mathrm{IIIE})\nu\\
&\quad+\sin\phi R\cdot\cos\phi\omega\cdot(\mathrm{PE})\nu]\\
&+R^2\cdot\sin2\phi R\cdot(\mathrm{IIE})\nu\}\quad\cdots(4B)
\end{aligned}
$$

【0040】ただし、偏心収差係数は以下の式(4C)～(4H)で定義される。

$$(\Delta E)\nu=-2\cdot(\alpha'\nu-\alpha\nu)\quad\cdots(4C)$$

$$
\begin{aligned}
(\mathrm{VE1})\nu=&\{[\alpha'\nu\cdot(\mu=\nu+1\to k)\,\Sigma V\mu]-[\alpha\nu\cdot(\mu=\nu\to k)\,\Sigma V\mu]\}\\
&-\{[\alpha'\#\nu\cdot(\mu=\nu+1\to k)\,\Sigma\,\mathrm{III}\mu]-[\alpha\#\nu\cdot(\mu=\nu\to k)\,\Sigma\,\mathrm{III}\mu]\}\quad\cdots(4D)
\end{aligned}
$$

$$(\mathrm{VE2})\nu=[\alpha'\#\nu\cdot(\mu=\nu+1\to k)\,\Sigma P\mu]-[\alpha\#\nu\cdot(\mu=\nu\to k)\,\Sigma P\mu]\quad\cdots(4E)$$

$$
\begin{aligned}
(\mathrm{IIIE})\nu=&\{[\alpha'\nu\cdot(\mu=\nu+1\to k)\,\Sigma\,\mathrm{III}\mu]-[\alpha\nu\cdot(\mu=\nu\to k)\,\Sigma\,\mathrm{III}\mu]\}\\
&-\{[\alpha'\#\nu\cdot(\mu=\nu+1\to k)\,\Sigma\,\mathrm{II}\mu]-[\alpha\#\nu\cdot(\mu=\nu\to k)\,\Sigma\,\mathrm{II}\mu]\}\quad\cdots(4F)
\end{aligned}
$$

$$(\mathrm{PE})\nu=[\alpha'\nu\cdot(\mu=\nu+1\to k)\,\Sigma P\mu]-[\alpha\nu\cdot(\mu=\nu\to k)\,\Sigma P\mu]\quad\cdots(4G)$$

$$
\begin{aligned}
(\mathrm{IIE})\nu=&\{[\alpha'\nu\cdot(\mu=\nu+1\to k)\,\Sigma\,\mathrm{II}\mu]-[\alpha\nu\cdot(\mu=\nu\to k)\,\Sigma\,\mathrm{II}\mu]\}\\
&-\{[\alpha'\#\nu\cdot(\mu=\nu+1\to k)\,\Sigma\,\mathrm{I}\mu]-[\alpha\#\nu\cdot(\mu=\nu\to k)\,\Sigma\,\mathrm{I}\mu]\}\quad\cdots(4H)
\end{aligned}
$$

【0041】上記式(4C)～(4H)の偏心収差係数は、偏心による影響を表しており、それぞれ以下の内容の結像の欠陥を代弁する働きをする。また、式(4A)，(4B)から分かるように、偏心量Eνは右辺全体にかかるので、偏心によって発生する収差の量はEνに比例する。

(ΔE)ν：プリズム作用(像の横ずれ)。

(VE1)ν，(VE2)ν：回転非対称な歪曲。

(IIIE)ν，(PE)ν：回転非対称な非点収差，像面の傾き。

(IIE)ν：軸上にも現れる回転非対称なコマ収差。

【0042】式(4A)～(4H)は、第νエレメントDνのみが平行偏心した場合を示しているが、この第νエレメントDνが単一面から成るとすれば、複数の面i～jが平行偏心する場合(つまり、偏心するレンズ群が第i面から第j面から成る場合)には、偏心する各面i～jの偏心量Ei～Ejは等しいので、式：(ΔE)i～j＝(ν=i→j)Σ[−2·(α′ν−αν)]で示すように、収差係数を和として扱うことができる。そして、α′ν＝αν+1より、式：(ΔE)i～j＝−2·(α′j−αi)が得られる。

【0043】その他の収差係数についても、同様にΣの途中の項が消える。例えばPEでは、

$$
\begin{aligned}
(\mathrm{PE})i\sim j&=(\nu=i\to j)\,\Sigma[\alpha'\nu\cdot(\mu=\nu+1\to k)\,\Sigma P\mu-\alpha\nu\cdot(\mu=\nu\to k)\,\Sigma P\mu]\\
&=\alpha'j\cdot(\mu=j+1\to k)\,\Sigma P\mu-\alpha i\cdot(\mu=i\to k)\,\Sigma P\mu\\
&=(\alpha'j-\alpha i)\cdot(\mu=j+1\to k)\,\Sigma P\mu-\alpha i\cdot(\mu=i\to j)\,\Sigma P\mu\\
&=(\alpha'j-\alpha i)\cdot(P)R-\alpha i\cdot(P)D
\end{aligned}
$$

ここで、

(P)R＝(μ=j+1→k)ΣPμ：偏心するレンズ群(以下「偏

心群」ともいう。）より像側に位置するすべてのレンズ面から成る群（以下「像側群」ともいう。）の収差係数Pの和、

$(P)D=(\mu=i\to j)\Sigma P\mu$　：偏心群の収差係数Pの和

である。したがって、偏心収差係数のΣは、像側群の収差係数の和｛( )Rで表現する。｝と、偏心群の収差係数の和｛( )Dで表現する。｝と、で表すことができる。

【００４４】［片ボケ収差］次に、片ボケ収差を説明する。式(4A),(4B)から、非点収差のメリディオナルは、[ΔY'の(Rの１次項)φR=0]×g'$kであり、サジタルは[ΔZ'の(Rの１次項)φR=π/2]×g'$kである。したがって、メリディオナル片ボケΔMνは、以下の式(5A)で表される。ここで、α'k=N'k/g'$k，φω=0より、式(5B)が得られる。

$$\Delta M\nu=-[E\nu\cdot g'\$k/(2\cdot\alpha'k)]\cdot 2\cdot(N\cdot\tan\omega)\cdot[(2\cdot\cos(\phi\omega)+\cos(\phi\omega))\cdot(IIIE)\nu+\cos(\phi\omega)\cdot(PE)\nu]\quad\cdots(5A)$$

$$\Delta M\nu=-E\nu\cdot(g'\$k^2/N'k)\cdot(N\cdot\tan\omega)\cdot[3\cdot(IIIE)\nu+(PE)\nu]\quad\cdots(5B)$$

【００４５】物点OPを無限遠とすると、g'$k→FL(FL:全系の焦点距離)，N·tanω=Y'/FL(Y':像高)なので、メリディオナル片ボケΔM'νを表す式(5C)が得られる。同様にして、サジタル片ボケΔS'νを表す式(5D)が得られる。

$$\Delta M'\nu=-E\nu\cdot FL\cdot Y'\cdot[3\cdot(IIIE)\nu+(PE)\nu]\quad\cdots(5C)$$

$$\Delta S'\nu=-E\nu\cdot FL\cdot Y'\cdot[(IIIE)\nu+(PE)\nu]\quad\cdots(5D)$$

【００４６】以上は第ν面が偏心した場合であるが、レンズ群（第i面から第j面で構成される）が偏心した場合にはΣをとって、メリディオナル片ボケ(ΔM')i～j，サジタル片ボケ(ΔS')i～jを表す式(5E),(5F)が得られる。ここで、偏心量をEとする。

$$(\Delta M')i\sim j=-E\cdot FL\cdot Y'\cdot[3\cdot(IIIE)i\sim j+(PE)i\sim j]\quad\cdots(5E)$$

$$(\Delta S')i\sim j=-E\cdot FL\cdot Y'\cdot[(IIIE)i\sim j+(PE)i\sim j]\quad\cdots(5F)$$

ただし、ブロック（レンズ群）の偏心収差係数は、以下の式(5G),(5H)でメリディオナル，サジタルのそれぞれについて表される。

$$[3\cdot(IIIE)i\sim j+(PE)i\sim j]=(\alpha'j-\alpha i)\cdot[3\cdot(III)R+(P)R]-\alpha i\cdot[3\cdot(III)D+(P)D]-(\alpha'\#j-\alpha\#i)\cdot[3\cdot(II)R]+\alpha\#i\cdot[3\cdot(II)D]\quad\cdots(5G)$$

$$[(IIIE)i\sim j+(PE)i\sim j]=(\alpha'j-\alpha i)\cdot[(III)R+(P)R]-\alpha i\cdot[(III)D+(P)D]-(\alpha'\#j-\alpha\#i)\cdot[(II)R]+\alpha\#i\cdot[(II)D]\quad\cdots(5H)$$

【００４７】［軸上コマ収差］次に、軸上コマ収差を説明する。軸上コマ収差は、前述したように、軸上光のUpperとLowerの主光線位置との差の平均値である。したがって、偏心によるUpperのコマ(ΔYU)νとLowerのコマ(ΔYL)νとから｛(6A),(6B)｝、式(6C)に示す軸上コマ収差(AXCM)νが導かれる。

$$(\Delta YU)\nu=(\Delta Y)(\omega=0,\phi R=0)-(\Delta Y)(\omega=0,R=0)$$
$$=-[E\nu/(2\cdot\alpha'k)]\cdot R^2\cdot 3\cdot(IIE)\nu\quad\cdots(6A)$$
$$(\Delta YL)\nu=(\Delta Y)(\omega=0,\phi R=\pi)-(\Delta Y)(\omega=0,R=0)$$
$$=-[E\nu/(2\cdot\alpha'k)]\cdot R^2\cdot 3\cdot(IIE)\nu\quad\cdots(6B)$$
$$(AXCM)\nu=[(\Delta YU)\nu+(\Delta YL)\nu]/2$$
$$=-[E\nu/(2\cdot\alpha'k)]\cdot R^2\cdot 3\cdot(IIE)\nu\quad\cdots(6C)$$

【００４８】物点を無限遠とすると、1/α'k→-FLとなる。また、RとFNO（全系のＦナンバー）との関係は、式：R=[FL/(2·FNO)]×κ（ここで、κ:瞳分割比，通常は0.7である。）で表される。したがって、軸上コマ収差(AXCM')νは、式(6D)で表される。

$$(AXCM')\nu=E\nu\cdot(3\cdot\kappa^2\cdot FL^3)/(8\cdot FNO^2)\cdot(IIE)\nu\quad\cdots(6D)$$

【００４９】以上は第ν面が偏心した場合であるが、レンズ群（第i面から第j面で構成される）が偏心した場合はΣをとって、式(6E)が得られる。ただし、ブロックの偏心収差係数は、式(6F)で表される。

$$(AXCM')i\sim j=E\cdot[(3\cdot\kappa^2\cdot FL^3)/(8\cdot FNO^2)]\cdot(IIE)i\sim j\quad\cdots(6E)$$

$$(IIE)i\sim j=(\alpha'j-\alpha i)\cdot(II)R-\alpha i\cdot(II)D-(\alpha'\#j-\alpha\#i)\cdot(I)R+\alpha\#i\cdot(I)D\quad\cdots(6F)$$

【００５０】〈傾き偏心収差係数の導出〉図２(B)は、第νエレメントDνが、光学系の基準軸AXに対して点Cを中心に角度ενだけ傾いた状態を示している。この傾き偏心による収差係数の付加項ΔY(εν)，ΔZ(εν)は、以下の式(7A),(7B)で表される。なお、点Cから第νエレメントDνの入射瞳面PS1，物体面OS；それらに対応する射出瞳面PS2，像面ISまでの距離を、それぞれpν，qν；p'ν，q'νとする。

$$\begin{aligned}\Delta Y(\varepsilon\nu)=&-[\varepsilon\nu/(2\cdot\alpha'k)]\cdot\{(\Delta\varepsilon)\nu\\&+(N\cdot\tan\omega)^2\cdot[(2+\cos2\phi\omega)\cdot(V\varepsilon1)\nu-(V\varepsilon2)\nu]\\&+2\cdot R\cdot(N\cdot\tan\omega)\cdot[(2\cdot\cos(\phi R-\phi\omega)+\cos(\phi R+\phi\omega))\cdot(III\varepsilon)\nu\\&+\cos\phi R\cdot\cos\phi\omega\cdot(P\varepsilon)\nu]\\&+R^2\cdot(2+\cos2\phi R)\cdot(II\varepsilon)\nu\}\quad\cdots(7A)\end{aligned}$$

$$\begin{aligned}\Delta Z(\varepsilon\nu)=&-[\varepsilon\nu/(2\cdot\alpha'k)]\cdot\{(N\cdot\tan\omega)^2\cdot\sin2\phi\omega\cdot(V\varepsilon1)\nu\\&+2\cdot R\cdot(N\cdot\tan\omega)\cdot[\sin(\phi R+\phi\omega)\cdot(III\varepsilon)\nu\end{aligned}$$

$$+\sin\phi_R\cdot\cos\phi_\omega\cdot(\mathrm{P}\varepsilon)_\nu]$$
$$+R^2\cdot\sin 2\phi_R\cdot(\mathrm{II}\varepsilon)_\nu\}\quad\cdots(7B)$$

【0051】ただし、偏心収差係数は以下の式(7C)～(7H)で定義される。

$$(\Delta\varepsilon)_\nu=-2\cdot(\alpha'_\nu\cdot q'_\nu-\alpha_\nu\cdot q_\nu)\quad\cdots(7C)$$

$$(\mathrm{V}\varepsilon 1)_\nu=\{[\alpha'_\nu\cdot q'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{V}_\mu]-[\alpha_\nu\cdot q_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{V}_\mu]\}-\{[\alpha'^{\#}_\nu\cdot p'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{III}_\mu]-[\alpha^{\#}_\nu\cdot p_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{III}_\mu]\}+[(\alpha'^{\#}_\nu/N'_\nu)-(\alpha^{\#}_\nu/N_\nu)]\quad\cdots(7D)$$

$$(\mathrm{V}\varepsilon 2)_\nu=\{[\alpha'^{\#}_\nu\cdot p'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{P}_\mu]-[\alpha^{\#}_\nu\cdot p_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{P}_\mu]\}+[(\alpha'^{\#}_\nu/N'_\nu)-(\alpha^{\#}_\nu/N_\nu)]\quad\cdots(7E)$$

$$(\mathrm{III}\varepsilon)_\nu=\{[\alpha'_\nu\cdot q'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{III}_\mu]-[\alpha_\nu\cdot q_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{III}_\mu]\}-\{[\alpha'^{\#}_\nu\cdot p'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{II}_\mu]-[\alpha^{\#}_\nu\cdot p_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{II}_\mu]\}\quad\cdots(7F)$$

$$(\mathrm{P}\varepsilon)_\nu=\{[\alpha'_\nu\cdot q'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{P}_\mu]-[\alpha_\nu\cdot q_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{P}_\mu]\}+[(\alpha'_\nu/N'_\nu)-(\alpha_\nu/N_\nu)]\quad\cdots(7G)$$

$$(\mathrm{II}\varepsilon)_\nu=\{[\alpha'_\nu\cdot q'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{II}_\mu]-[\alpha_\nu\cdot q_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{II}_\mu]\}-\{[\alpha'^{\#}_\nu\cdot p'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{I}_\mu]-[\alpha^{\#}_\nu\cdot p_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{I}_\mu]\}\quad\cdots(7H)$$

【0052】傾き偏心の場合も、平行偏心の場合と同様に、Σをとった場合について考える。偏心するレンズ群を第i面から第j面とすると、例えば、Pεでは、

$$(\mathrm{P}\varepsilon)_{i\sim j}=\sum_{\nu=i}^{j}\{\alpha'_\nu\cdot q'_\nu\cdot\sum_{\mu=\nu+1}^{k}\mathrm{P}_\mu-\alpha_\nu\cdot q_\nu\cdot\sum_{\mu=\nu}^{k}\mathrm{P}_\mu]+[(\alpha'_\nu/N'_\nu)-(\alpha_\nu/N_\nu)]\}$$
$$=\alpha'_j\cdot q'_j\cdot\sum_{\mu=j+1}^{k}\mathrm{P}_\mu-\alpha_i\cdot q_i\cdot\sum_{\mu=i}^{k}\mathrm{P}_\mu+\sum_{\nu=i}^{j}[(\alpha'_\nu/N'_\nu)-(\alpha_\nu/N_\nu)]$$
$$=(\alpha'_j\cdot q'_j-\alpha_i\cdot q_i)\cdot\sum_{\mu=j+1}^{k}\mathrm{P}_\mu-\alpha_i\cdot q_i\cdot\sum_{\mu=i}^{j}\mathrm{P}_\mu+[(\alpha'_j/N'_j)-(\alpha_i/N_i)]$$
$$=(\alpha'_j\cdot q'_j-\alpha_i\cdot q_i)\cdot(\mathrm{P})_R-\alpha_i\cdot q_i\cdot(\mathrm{P})_D+[(\alpha'_j/N'_j)-(\alpha_i/N_i)]$$

ここで、

$(\mathrm{P})_R=\sum_{\mu=j+1}^{k}\mathrm{P}_\mu$：像側群の収差係数Pの和、

$(\mathrm{P})_D=\sum_{\mu=i}^{j}\mathrm{P}_\mu$：偏心群の収差係数Pの和

である。したがって、偏心収差係数のΣは、像側群の収差係数の和と、偏心群の収差係数の和と、定数項と、で表すことができる。

【0053】［片ボケ収差］片ボケ収差は、平行偏心の場合と同様に行うと、メリディオナル片ボケ$(\Delta M')_{i\sim j}$，サジタル片ボケ$(\Delta S')_{i\sim j}$を表す式(8A)，(8B)で表される。ここで、偏心量をεとする。

$$(\Delta M')_{i\sim j}=-\varepsilon\cdot FL\cdot Y'\cdot[3\cdot(\mathrm{III}\varepsilon)_{i\sim j}+(\mathrm{P}\varepsilon)_{i\sim j}]\quad\cdots(8A)$$
$$(\Delta S')_{i\sim j}=-\varepsilon\cdot FL\cdot Y'\cdot[(\mathrm{III}\varepsilon)_{i\sim j}+(\mathrm{P}\varepsilon)_{i\sim j}]\quad\cdots(8B)$$

ただし、ブロックの偏心収差係数は、以下の式(8C)，(8D)でメリディオナル，サジタルのそれぞれについて表される。

$$[3\cdot(\mathrm{III}\varepsilon)_{i\sim j}+(\mathrm{P}\varepsilon)_{i\sim j}]=(\alpha'_j\cdot q'_j-\alpha_i\cdot q_i)\cdot[3\cdot(\mathrm{III})_R+(\mathrm{P})_R]-\alpha_i\cdot q_i[3\cdot(\mathrm{III})_D+(\mathrm{P})_D]-(\alpha'^{\#}_j\cdot p'_j-\alpha^{\#}_i\cdot p_i)\cdot[3\cdot(\mathrm{II})_R]+\alpha^{\#}_i\cdot p_i[3\cdot(\mathrm{II})_D]+[(\alpha'_j/N'_j)-(\alpha_i/N_i)]\quad\cdots(8C)$$

$$[(\mathrm{III}\varepsilon)_{i\sim j}+(\mathrm{P}\varepsilon)_{i\sim j}]=(\alpha'_j\cdot q'_j-\alpha_i\cdot q_i)\cdot[(\mathrm{III})_R+(\mathrm{P})_R]-\alpha_i\cdot q_i[(\mathrm{III})_D+(\mathrm{P})_D]-(\alpha'^{\#}_j\cdot p'_j-\alpha^{\#}_i\cdot p_i)\cdot[(\mathrm{II})_R]+\alpha^{\#}_i\cdot p_i[(\mathrm{II})_D]+[(\alpha'_j/N'_j)-(\alpha_i/N_i)]\quad\cdots(8D)$$

【0054】［軸上コマ収差］軸上コマも、平行偏心の場合と同様に行うと、式(9A)で示すようになる。ただし、ブロックの偏心収差係数は式(9B)で表される。

$$(AXCM')_{i\sim j}=\varepsilon\cdot[(3\cdot\kappa^2\cdot FL^3)/(8\cdot FNO^2)]\cdot(\mathrm{IIE})_{i\sim j}\quad\cdots(9A)$$

(IIε)i～j＝(α′j·q′j－αi·qi)·(II)R－αi·qi·(II)D－(α′#j·p′j－α#i·pi)·(I)R＋α#i·pi·(I)D　…(9B)

【００５５】《収差係数から見た偏心収差の特性》上述したように偏心収差は３次の収差係数で表現されるが、そこから分かる収差劣化の傾向と収差係数との関係を以下に説明する。

【００５６】〈偏心収差とスペック〉前述した『収差係数による偏心収差の導出』から、偏心収差は一般に以下の式(10A)で表すことができる。

[偏心収差]＝[偏心量]×[スペックの項]×[偏心収差係数]　…（１０Ａ）

【００５７】したがって、以下の①，②に挙げるように、偏心収差に対する敏感度は、スペックからある程度理解可能である。

①　片ボケ収差は、焦点距離と像高に比例して大きくなるので、焦点距離の大きな望遠レンズでは避けられない。また。レンズシャッターカメラと一眼レフカメラでは、片ボケ収差を評価する像高が違うので、同じ焦点距離では一眼レフカメラの方が、偏心収差に対する敏感度は大きくなる。

②　軸上コマ収差は、焦点距離の３乗に比例し、Ｆナンバー（ＦＮＯ）の２乗に反比例する。したがって、一眼レフカメラのようにズームでＦナンバーがほぼ一定ののでは、軸上コマ収差が焦点距離の３乗に比例するため、焦点距離が伸びると急激に偏心収差に対する敏感度が大きくなる。また。レンズシャッターカメラ用ズームレンズのように、焦点距離に応じてＦナンバーが大きくなるものは、焦点距離に比例して大きくなる。最近のレンズシャッターカメラ用高倍率ズームでは、Ｆナンバーは焦点距離ほど変化しないので、望遠になると急に偏心収差に対する敏感度が大きくなる。

【００５８】〈平行偏心収差の特性〉平行偏心収差係数は、一般に以下の式(11A)のように表現することができる。

(偏心収差係数)i～j＝(α′j－αi)·(収差係数１の和)R
　－αi·(収差係数１の和)D
　－(α′#j－α#i)·(収差係数２の和)R
　＋α#i·(収差係数２の和)D　…(11A)

【００５９】式(11A)において、第１項と第２項は(収差係数１の和)、第３項と第４項は(収差係数２の和)であるが、具体的には、

(片ボケ収差の場合)…

(収差係数１)＝[非点収差係数(III)]＋[ペッツバール和(P)]

(収差係数２)＝[コマ収差係数(II)]

(軸上コマ収差の場合)…

(収差係数１)＝[コマ収差係数(II)]

(収差係数２)＝[球面収差係数(I)]

である。

【００６０】上記のように、偏心収差係数[式(11A)]は４つの項から成り立っている。以下に各項を説明する。

[第１項]…第１項の係数(α′j－αi)は、軸上のマージナル光線が偏心群でどれほど曲げられるか、すなわち偏心群のパワーを表している。特に、偏心群が最も物体側にあるときにはパワーそのものであり、オーダー的には10の-2乗程度とそう大きくない。

[第２項]…第２項の係数-αiは、偏心群に入射する軸上光のマージナル光線の角度である。したがって、値はあまり大きくない。一般に、偏心群が物体側にあるほど小さく、特に最も物体側にあるとき、この項は全く寄与しないのが特徴である。

[第３項]…第３項の係数-(α′#j－α#i)は、偏心群での主光線の曲がり具合を表しており、一般的には偏心群が絞りから離れるほど大きい。オーダーは10の-1～1乗程度である。

[第４項]…第４項の係数α#iは、偏心群に入射する主光線の角度であり、初期値は-1である。値もあまり変化せず、せいぜい-5程度まででである。

【００６１】(収差係数１)と(収差係数２)の大きさの関係は、(収差係数１)の方が(収差係数２)に対して１０の１～２乗程度大きい。また、(収差係数２)は、(収差係数１)と比較して変化させ易い。以上のことを考慮に入れると、一般的に、常に大きな値を持つのは第４項である。他の項は、絞りの位置や偏心群のパワーによって影響が大きくなったり小さくなったりする。したがって、通常の光学系においては第４項を極小化するのが望ましい。ただし、光学系の構成に応じて他の項を極小化するのが望ましい場合もありうる。

【００６２】〈傾き偏心収差の特性〉傾き偏心収差係数は、一般に以下の式(12A)のように表現することができる。

(偏心収差係数)i～j＝(α′j·q′j－αi·qi)·(収差係数１の和)R
　－αi·qi·(収差係数１の和)D
　－(α′#j·p′j－α#i·pi)·(収差係数２の和)R
　＋α#i·pi·(収差係数２の和)D
　＋[(α′j/N′j)－(αi/Ni)](←定数項は片ボケの場合のみ

$) \quad \cdots (12A)$

【0063】傾き偏心収差係数は、その中に回転中心Cからの物体距離qや回転中心Cからの入射瞳位置pが入っているために、このままでは計算が煩雑である。そこで、回転中心Cを偏心群の物体側面の面頂点とし、偏心群の前後が空気であるとすると、以下のように置き換えることができる。

$$\alpha'j \cdot q'j = \alpha'j \cdot s'j + \alpha'j \cdot TD$$
$$= hj + \alpha'j \cdot TD \quad \cdots (12B)$$
$$\alpha i \cdot qi = hi \quad \cdots (12C)$$
$$\alpha'\#j \cdot p'j = h\#j + \alpha'\#j \cdot TD \quad \cdots (12D)$$
$$\alpha\#i \cdot pi = h\#i \quad \cdots (12E)$$

ただし、

hi　：第i面での近軸軸上マージナル光線の高さ、
h#i　：第i面での近軸軸外主光線の高さ、
hj　：第j面での近軸軸上マージナル光線の高さ、
h#j　：第j面での近軸軸外主光線の高さ、
TD　：偏心群の芯厚（すなわち、第i面から第j面までの軸上面間隔）

である。

【0064】上式(12B)～(12E)を用いて、式(8C)，(8D)；(9B)の傾き偏心収差係数をもう一度表現すると、次式(12F)，(12G)；(12H)のようになる。

（メリディオナル片ボケ収差）

$$\begin{aligned}[3\cdot(\mathrm{III}\varepsilon)i\sim j+(P\varepsilon)i\sim j] &= (hj-hi+\alpha'j\cdot TD)\cdot[3\cdot(\mathrm{III})R+(P)R] \\ &\quad -hi\cdot[3\cdot(\mathrm{III})D+(P)D] \\ &\quad -(h\#j-h\#i+\alpha'\#j\cdot TD)\cdot[3\cdot(\mathrm{II})R] \\ &\quad +h\#i\cdot[3\cdot(\mathrm{II})D] \\ &\quad +(\alpha'j-\alpha i) \quad \cdots (12F)\end{aligned}$$

（サジタル片ボケ収差）

$$\begin{aligned}[(\mathrm{III}\varepsilon)i\sim j+(P\varepsilon)i\sim j] &= (hj-hi+\alpha'j\cdot TD)\cdot[(\mathrm{III})R+(P)R] \\ &\quad -hi\cdot[(\mathrm{III})D+(P)D] \\ &\quad -(h\#j-h\#i+\alpha'\#j\cdot TD)\cdot[(\mathrm{II})R] \\ &\quad +h\#i\cdot[(\mathrm{II})D] \\ &\quad +(\alpha'j-\alpha i) \quad \cdots (12G)\end{aligned}$$

（軸上コマ収差）

$$\begin{aligned}(\mathrm{II}\varepsilon)i\sim j &= (hj-hi+\alpha'j\cdot TD)\cdot(\mathrm{II})R \\ &\quad -hi(\mathrm{II})D \\ &\quad -(h\#j-h\#i+\alpha'\#j\cdot TD)\cdot(\mathrm{I})R \\ &\quad +h\#i\cdot(\mathrm{I})D \quad \cdots (12H)\end{aligned}$$

【0065】結局、傾き偏心収差係数は、一般に以下の式(13A)のように表現することができる。ただし、偏心群の前後が空気で、偏心群の面頂点を中心に傾く場合である。

$$\begin{aligned}(\text{偏心収差係数})i\sim j &= (hj-hi+\alpha'j\cdot TD)\cdot(\text{収差係数1の和})R \\ &\quad -hi\cdot(\text{収差係数1の和})D \\ &\quad -(h\#j-h\#i+\alpha'\#j\cdot TD)\cdot(\text{収差係数2の和})R \\ &\quad -h\#i\cdot(\text{収差係数2の和})D \\ &\quad +(\alpha'j-\alpha i)\ (\leftarrow\text{定数項は片ボケの場合のみ}) \quad \cdots (13A)\end{aligned}$$

【0066】上記のように、傾き偏心収差係数は、軸上コマ収差では４つの項から成り立っており、片ボケ収差では５つの項から成り立っている。以下に各項を説明する。

[第１項]…初期値h1=1で変化は0.1～3程度であるが、群の中ではあまり変化しないので、hj-hiは0.1程度、芯厚TDはレンズシャッターカメラでは1～10、一眼レフカメラでは5～50程度である。α′jは10の-2乗程度である。

[第２項]…hiは0.1～3程度である。

[第３項]…h#iはおおよそ絞りからの距離とみなせるので、h#j-h#i≒TDである。また、α′#jは初期値が1で10の-1～1乗程度である。

[第４項]…h#iはおおよそ絞りからの距離なので、最も変化が大きく、1～50程度である。

[第５項]…片ボケ収差のみにかかる項であり、３次収差係数を含まない定数項である。値は10の-2乗程度である。

【0067】また、収差係数の大きさの関係は、球面収差係数(I)が1×10^{-4}、コマ収差係数(II)が50×10^{-4}、非点収差係数(III)とペッツバール和(P)が500×10^{-4}である。以上のことを考慮に入れると、片ボケ収差では、第１項，第２項，第５項が大きな値を持ち、第４項は絞りの位置によっては非常に大きくなったり無視できたりする。特に、第５項が大きな値を持つのは、すべての収差係数が０でも値を持つことを意味している。したがって、傾き偏心と平行偏心の誤差感度を両方共低くすることの難しさが理解できる。また、軸上コマ収差では、第３項と第４項が支配的になるが、第４項は絞り位置によ

って大きく変化する。以上のように、傾き偏心と平行偏心とで支配的な項が異なっているため、一つの収差係数を小さくすれば、両方の感度が小さくなるわけではないことが分かる。

【0068】《偏心収差の解析から導き出される望ましい実施の形態》上述した偏心収差の導出等から分かるように、任意の光学系において、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも1つのレンズ面から成る群(前記偏心群に相当し、例えばレンズ群やレンズ面である。)に対し、偏心誤差感度を大きくする主要因となっている3次収差係数を小さくする設計を行えば、その光学系での偏心による誤差感度が小さくなる。本発明に係る光学系，その製造方法及び偏心誤差感度低減設計方法は、この点に着目してなされたものであり、その特徴の一つは、以下に説明する5つの段階から成る特徴的設計手法にある。

【0069】〈第1段階〉第1段階は、偏心誤差感度が相対的に大きいために製造上問題となる、少なくとも1つのレンズ面から成る群(以下「特定群」ともいう。)を特定することを特徴とする(図3，＃10)。具体的には、対象となる光学系の各要素，レンズブロック，レンズ，レンズ面に、実際に偏心(平行偏心と傾き偏心)が発生した場合の偏心収差の発生の程度を、例えば光線追跡によって調査する。そのときに注目すべき偏心収差は、前述した「片ボケ収差」と「軸上コマ収差」である。

【0070】近年、光学系の分野ではズームレンズの設計が活発に行われており、ズーム比の向上や小型化の技術が数多く発表されている。しかし、ズーム比の向上や小型化は、一般的に誤差感度を大きくする傾向にある。高倍率化や小型化が進むと製造精度を向上させる必要があるが、現状では追いついていない。このため倍率や大きさは製造の限界から決定されているが、市場の要求は高倍率・小型のものを求める動きが大きいため、満足なズームレンズは提供されていない。

【0071】ズームレンズの場合、調心技術によって、ズームブロックの中では、ある程度の偏心誤差感度が吸収可能になってきている。しかし、ズーミングの間移動するズームブロックでは、高精度の調心を行うことができないのが現状である。この点で、本発明の特徴的設計手法は、ズームレンズに好適である。ズームレンズに適用した場合、ズームブロックを特定群とするのが好ましく、更に好ましくは、特定群が偏心誤差感度の最も大きなズーム群であるのが良い。

【0072】本発明に係る特徴的設計手法は、光学系のただ一つの要素の偏心誤差感度を低減するために留まらない。その設計手法を繰り返し用いることで、光学系のすべての要素が製造誤差に対して十分許容できるくらい小さな偏心誤差感度を有する構成とすることができる。したがって、ズームブロックの偏心誤差感度の小さなズーム光学系においては、対象となる要素はレンズ又はレンズ面であることが望ましい。ズームブロック内の誤差感度を低減することができれば、調心を行う必要がなくなって、製造上有利になるからである。

【0073】対象となる光学系が単焦点レンズである場合、以下の条件式(1)を満足することが望ましい。

$fL/ymax>3$ …(1)

ただし、

fL：全系の焦点距離、

$ymax$：画面対角長

である。

【0074】上記条件式(1)は、単焦点レンズの焦点距離を表している。前述した偏心収差の導出から分かるように、誤差感度は焦点距離が大きくなるほど目立つようになる。したがって、あまりに短い焦点距離の光学系では、もともと誤差感度が小さいので、低減の必要性がない場合が多い。

【0075】〈第2段階〉第2段階は、前記第1段階で特定された群(特定群)の偏心収差係数を用いて偏心収差を計算し、その計算によって得られた偏心収差と、実際の偏心収差(例えば、光線追跡で得られたもの)と、の比較を行うことを特徴とする(図3，＃20)。前述した偏心収差の導出から分かるように、偏心収差係数は各収差係数(3次収差係数)の1次結合で表される。通常の光学系において、偏心収差係数から導出された偏心収差の値と、光線追跡により得られた実際の偏心収差の値と、を比較してみると非常によく一致する。これは、3次収差係数から計算される収差が実際の収差と良く一致するということからも理解できる。しかし、光学系に多くの非球面がある場合には、高次収差が過大に発生する場合があり、そのときは3次収差係数から計算される収差と実際の収差とが一致しないことになる。当然、偏心収差係数から導出される偏心収差と実際の偏心収差とで値が大きく異なることになるため、解析的な設計を行うことが難しくなる。

【0076】上記のように解析的な設計が困難なとき(つまり、計算によって得られた偏心収差と実際の偏心収差とが大きく異なると判断した場合)は、偏心状態での点像分布の大きさを極小化するように設計するのが望ましい(図3，＃60)。このように設計することにより、偏心収差を小さく抑えて、偏心誤差感度を低減することができる。具体的には、弱くしたい偏心誤差感度の部分を偏心させたポジションを実際に作り、追加ポジションにし、通常状態のポジションに加えて、追加した偏心ポジションにも設計のウエイトを加えて、偏心状態での点像を小さくする設計を行う。偏心状態のウエイトを大きくすることで点像が小さくなり、かつ、通常状態の性能も保持することができれば、偏心誤差感度を小さくすることができたことになる。できない場合には、非球面，ズーム解，レンズ等の自由度を適当に付加することによって、偏心誤差感度低減の可能性を探せばよい。

【0077】〈第3段階〉第3段階は、前記第2段階での比較の結果、偏心収差係数を用いた計算によって得られた偏心収差と光線追跡により得られた実際の偏心収差とがよく一致すると判断した場合、偏心誤差感度を大きくする主要因となっている3次収差係数を特定することを特徴とする(図3，＃30)。偏心収差係数に支配的な3次収差係数が偏心誤差感度を大きくする主要因となるので、特定群の偏心収差が偏心収差係数のどの項の影響を最も受けているかを調べる。偏心収差係数の各項の値(又は各項についての偏心収差)から、偏心収差係数に最も支配的な項を特定する。その項が特定できれば、どの3次収差係数が支配的であるかの特定は簡単に行うことができる。特定する3次収差係数は、1つであっても2つ以上であってもよい。特定される3次収差係数は、片ボケ収差の場合、特定群のコマ収差係数(II)であることが一般的であり、軸上コマ収差の場合、特定群の球面収差(I)であることが一般的である。

【0078】〈第4段階〉第4段階は、前記第3段階で特定された3次収差係数を小さくする設計を行うことを特徴とする(図3，＃40)。この第4段階は、第3段階の解析の結果を受けて、具体的に設計を行う段階である。第3段階で特定された3次収差係数が、対象となる要素(特定群)の3次収差係数{( )D}である場合、第4段階で3次収差係数を小さくしようとしても、特定群が小さな3次収差係数を取り得ないことがある。その際に、対象となる要素に自由度の付加を行うことで、所望の3次収差係数を達成させることが望ましい。自由度の付加とは、例えば、非球面の付加，レンズの追加である。

【0079】第3段階で特定された3次収差係数が、特定群より像側に位置するすべてのレンズ面から成る群(像側群)の3次収差係数{( )R}である場合、第4段階で3次収差係数を小さくしようとしても、その像側群が小さな3次収差係数を取り得ないことがある。その際、特定群の像側(すなわち、像側群)に自由度の付加を行うことで、所望の3次収差係数を達成させることが望ましい。自由度の付加とは、例えば、非球面の付加，レンズの追加である。

【0080】〈第5段階〉第5段階は、全体性能が前記第4段階での設計の前の状態(元の状態)と同程度に維持されるように、第4段階での設計に伴って変動した収差バランスを整える設計を行うことを特徴とする(図3，＃50)。第4段階で特定の要素(特定群や像側群)の3次収差係数を大きく変動させたので、全体の3次収差係数は大きな値になっている。そこで、第4段階で設計に用いた要素以外を設計変数として、全体の3次収差係数を小さくするように設計を行う。

【0081】第4段階で収差変動が大きすぎると、全体収差を元の状態と同程度にすることが困難になる場合がある。その際に、特定群の物体側(例えば、物体側に位置するレンズ群)に自由度の付加を行うことが望ましい。自由度の付加とは、例えば、非球面の付加，レンズの追加である。前述した偏心収差の導出等から明らかなように、偏心誤差感度は、対象となる要素(特定群)の物体側に位置するレンズ群の収差係数からは全く影響を受けない。したがって、特定群の物体側に自由度を加えて大きく収差係数を変動させても、特定群の偏心誤差感度には影響無しに、全体性能を元の状態と同等にすることができる。

【0082】《本発明に係る偏心誤差感度低減設計と従来の設計との違い》先に述べたように、従来も誤差感度に関して設計が行われていなかったわけではなく、ある程度の誤差感度低減は行われていた。その考え方は、誤差感度の大きな部分のパワーを弱くすることで感度を小さくするというものであって、結局、誤差感度を弱くすることは、光学系を大きくすることになっていた。本発明に係る特徴的設計手法によれば、前述したように偏心誤差感度を収差係数から解析することによって、同じパワーであっても偏心誤差感度の小さな解の存在を明らかにし、従来では性能やスペックを向上させるために用いられてきた非球面等を偏心収差係数の絶対値を小さくするために導入することによって、偏心誤差感度を低減することが可能である。図4に、偏心誤差感度を低減するための、本発明に係る特徴的設計手法と従来の設計手法との違いについてのイメージ図を示す。

【0083】

【実施例】以下、本発明を実施したズームレンズの構成を、コンストラクションデータ，収差図等を挙げて、更に具体的に説明する。各実施例及び比較例のコンストラクションデータにおいて、ri (i=1, 2, 3, . . .) は物体側から数えてi番目の面の曲率半径、di (i=1, 2, 3, . . .) は物体側から数えてi番目の軸上面間隔を示しており、Ni (i=1, 2, 3, . . .), νi (i=1, 2, 3, . . .) は物体側から数えてi番目のレンズのd線に対する屈折率(Nd)，アッベ数(νd)を示している。また、コンストラクションデータ中、ズーミングにおいて変化する軸上面間隔(可変間隔)は、広角端(短焦点距離端)[W]～ミドル(中間焦点距離状態)[M]～望遠端(長焦点距離端)[T]での各群間の軸上間隔である。各焦点距離状態[W]，[M]，[T]に対応する全系の焦点距離f及びFナンバーFNOを併せて示す。

【0084】曲率半径riに*印が付された面は、非球面で構成された面であることを示し、非球面の面形状を表わす次の式(AS)で定義されるものとする。

$$X=(C\cdot Y^2)/\{1+(1-\varepsilon\cdot Y^2\cdot C^2)^{1/2}\}+\Sigma(Ai\cdot Y^i) \quad \cdots (AS)$$

ただし、式(AS)中、

X ：光軸方向の基準面からの変位量、

Y ：光軸に対して垂直な方向の高さ、

C ：近軸曲率、

ε ：2次曲面パラメータ、

Ai：i次の非球面係数

である。

【0085】
《比較例(正・負・正・正)》
f=22.75～60.00～155.40
FNO= 4.60～ 5.22～ 5.80
［曲率半径］［軸上面間隔］［屈折率］ ［アッベ数］
r1= 80.507
d1= 1.500 N1= 1.83350 ν1= 21.00
r2= 50.638
d2= 0.010 N2= 1.51400 ν2= 42.83
r3= 50.638
d3= 6.300 N3= 1.60311 ν3= 60.74
r4= -590.399
d4= 0.100
r5= 36.741
d5= 4.330 N4= 1.49310 ν4= 83.58
r6= 91.218
d6= 1.300～19.406～33.552
r7*= 91.218
d7= 1.300 N5= 1.76743 ν5= 49.48
r8= 11.256
d8= 4.440
r9= -33.551
d9= 1.000 N6= 1.75450 ν6= 51.57
r10= 45.126
d10= 0.100
r11= 22.081
d11= 2.780 N7= 1.83350 ν7= 21.00
r12= -81.335
d12= 1.290
r13= -26.837
d13= 1.000 N8= 1.75450 ν8= 51.57
r14= 267.900
d14=14.735～7.506～1.200
r15= ∞(絞りA)
d15= 0.720
r16= 19.552
d16= 3.700 N9= 1.51823 ν9= 58.96
r17= -70.651
d17= 0.100
r18= 20.750
d18= 4.000 N10=1.48749 ν10=70.44
r19= -30.525
d19= 1.350
r20= -19.354
d20= 1.000 N11=1.84666 ν11=23.82
r21= 266.334
d21= 4.800～1.900～0.700
r22= 25.488
d22= 4.240 N12=1.51742 ν12=52.15
r23= -18.130
d23= 1.600
r24*= -31.725
d24= 1.400 N13=1.76743 ν13=49.48
r25*= 29.200
d25= 1.250
r26= 30.049
d26= 2.150 N14=1.67339 ν14=29.25
r27= 220.193

【0086】［第7面(r7)の非球面データ］
ε = 1.0000
A4=-0.71639468×10^{-6}
A6= 0.52909389×10^{-7}
A8=-0.15444212×10^{-8}
A10= 0.14666388×10^{-10}
A12=-0.50346363×10^{-13}

【0087】［第24面(r24)の非球面データ］
ε = 1.0000
A4=-0.12662318×10^{-4}
A6=-0.18371721×10^{-5}
A8= 0.64823035×10^{-7}
A10=-0.16739676×10^{-8}
A12= 0.15325296×10^{-10}

【0088】［第25面(r25)の非球面データ］
ε = 1.0000
A4= 0.80098384×10^{-4}
A6=-0.14551791×10^{-5}
A8= 0.54084513×10^{-7}
A10=-0.12612528×10^{-8}
A12= 0.10743852×10^{-10}

【0089】

《実施例１(正・負・正・正)》

f =22.75～60.00～155.47

FNO= 4.60～ 5.22～ 5.80

[曲率半径] [軸上面間隔] [屈折率] [アッベ数]

r1= 67.212
d1= 0.850 N1= 1.83350 ν1= 21.00
r2= 46.411
d2= 0.010 N2= 1.51400 ν2= 42.83
r3= 46.411
d3= 5.611 N3= 1.60311 ν3= 60.74
r4=-1533.625
d4= 0.100
r5= 37.479
d5= 3.192 N4= 1.49310 ν4= 83.58
r6= 80.254
d6= 1.300～18.806～33.718
r7*= 55.942
d7= 1.885 N5= 1.76743 ν5= 49.48
r8= 11.445
d8= 5.063
r9= -23.786
d9= 0.850 N6= 1.75450 ν6= 51.57
r10= 76.080
d10= 0.100
r11= 30.979
d11= 2.383 N7= 1.83350 ν7= 21.00
r12= -51.984
d12= 3.062
r13= -14.519
d13= 0.850 N8= 1.75450 ν8= 51.57
r14= -33.010
d14=15.174～7.640～1.200
r15= ∞(絞りＡ)
d15= 0.100
r16= 18.695
d16= 3.912 N9= 1.51823 ν9= 58.96
r17= -76.828
d17= 0.117
r18= 17.787
d18= 5.364 N10=1.48749 ν10=70.44
r19=-191.752
d19= 0.100
r20=-1380.472
d20= 1.305 N11=1.84666 ν11=23.82
r21*= 22.105
d21= 4.450～0.372～0.700
r22= 13.823
d22= 2.946 N12=1.51742 ν12=52.15
r23= -38.168
d23= 0.100
r24*=203.761
d24= 0.850 N13=1.76743 ν13=49.48
r25*= 15.784
d25= 5.907
r26= 41.896
d26= 1.417 N14=1.67339 ν14=29.25
r27= 183.628

【００９０】[第７面(r7)の非球面データ]

ε = 1.0000
A4= 0.13382026×10^{-4}
A6= 0.98519488×10^{-7}
A8= -0.20533289×10^{-8}
A10= 0.14078856×10^{-10}
A12= $-0.28051717\times10^{-13}$

【００９１】[第２１面(r21)の非球面データ]

ε = 1.0000
A4= 0.56033831×10^{-4}
A6= 0.20859596×10^{-6}
A8= -0.89435819×10^{-9}
A10= $-0.32902126\times10^{-10}$
A12= 0.14244659×10^{-11}

【００９２】[第２４面(r24)の非球面データ]

ε = 1.0000
A4= 0.24244833×10^{-5}
A6= -0.18608783×10^{-5}
A8= 0.65868793×10^{-7}
A10= -0.15356660×10^{-8}
A12= 0.15529677×10^{-10}

【００９３】[第２５面(r25)の非球面データ]

ε = 1.0000
A4= 0.52954566×10^{-4}
A6= -0.15597732×10^{-5}
A8= 0.56109687×10^{-7}
A10= -0.13012153×10^{-8}
A12= 0.13945660×10^{-10}

【００９４】

《実施例２(正・負・正・正・正)》
f =22.50～68.20～215.01
FNO= 4.10～ 5.20～ 5.80
[曲率半径] [軸上面間隔] [屈折率] [アッベ数]
r1= 83.031
d1= 0.900 N1= 1.80518 ν1= 25.43
r2= 58.244
d2= 8.632 N2= 1.49310 ν2= 83.58
r3= -578.162
d3= 0.100
r4= 50.487
d4= 5.067 N3= 1.49310 ν3= 83.58
r5= 130.665
d5= 1.500～27.727～47.883
r6= 54.141
d6= 0.900 N4= 1.69100 ν4= 54.75
r7= 13.636
d7= 6.568
r8= -43.963
d8= 0.900 N5= 1.75450 ν5= 51.57
r9= 68.381
d9= 0.100
r10= 22.995
d10= 3.675 N6= 1.75000 ν6= 25.14
r11= -76.156
d11= 1.991
r12= -27.803
d12= 0.900 N7= 1.75450 ν7= 51.57
r13= 76.918
d13=23.778～12.929～1.400
r14= ∞(絞りＡ)
d14= 0.100
r15= 23.349
d15= 2.694 N8= 1.51680 ν8= 64.20
r16=-109.602
d16= 0.100
r17= 17.126
d17= 3.780 N9= 1.48749 ν9= 70.44
r18= 54.839
d18= 2.069
r19=1000.170
d19= 0.960 N10=1.84666 ν10=23.82
r20*= 26.326
d20= 5.000～0.731～0.717
r21= 16.450
d21= 3.458 N11=1.51742 ν11=52.15
r22= -41.645
d22= 0.100
r23= 107.729
d23= 1.269 N12=1.80518 ν12=25.43
r24=-234.940
d24= 0.678
r25*=308.495
d25= 0.900 N13=1.85000 ν13=40.04
r26*= 19.631
d26= 1.743
r27= 34.180
d27= 0.900 N14=1.62280 ν14=56.88
r28= 28.353
d28= 2.500～15.493～13.880
r29= 27.227
d29= 1.641 N15=1.85000 ν15=40.04
r30= 36.334

【００９５】[第２０面(r20)の非球面データ]
ε = 1.0000
A4= $0.29375182 \times 10^{-4}$
A6= $-0.61263568 \times 10^{-7}$
A8= $0.72651555 \times 10^{-9}$
A10= $0.14884299 \times 10^{-10}$
A12= $-0.22214701 \times 10^{-12}$

【００９６】[第２５面(r25)の非球面データ]
ε = 1.0000
A4= $0.59719107 \times 10^{-5}$
A6= $-0.15750654 \times 10^{-6}$
A8= $-0.76280738 \times 10^{-8}$
A10= $-0.18941169 \times 10^{-10}$
A12= $0.12179777 \times 10^{-11}$
A14= $0.19818816 \times 10^{-13}$
A16= $-0.35165979 \times 10^{-15}$

【００９７】[第２６面(r26)の非球面データ]
ε = 1.0000
A4= $0.53641668 \times 10^{-4}$
A6= $0.64473049 \times 10^{-6}$
A8= $-0.19461151 \times 10^{-7}$
A10= $-0.42546389 \times 10^{-10}$
A12= $0.38972037 \times 10^{-11}$
A14= $0.38043446 \times 10^{-13}$
A16= $-0.94934519 \times 10^{-15}$

【００９８】

《実施例３(正・負・正・正)》

f =22.75〜60.00〜155.40

FNO= 4.60〜 5.22〜 5.80

[曲率半径]	[軸上面間隔]	[屈折率]	[アッベ数]
r1= 73.644			
	d1= 0.850	N1= 1.83350	ν1= 21.00
r2= 49.348			
	d2= 0.010	N2= 1.51400	ν2= 42.83
r3= 49.348			
	d3= 6.787	N3= 1.60311	ν3= 60.74
r4= -712.296			
	d4= 0.100		
r5= 35.459			
	d5= 3.967	N4= 1.49310	ν4= 83.58
r6= 74.524			
	d6= 1.300〜20.632〜33.920		
r7*= 46.570			
	d7= 0.850	N5= 1.76743	ν5= 49.48
r8= 10.755			
	d8= 4.530		
r9= -27.774			
	d9= 0.850	N6= 1.75450	ν6= 51.57
r10= 46.989			
	d10= 0.100		
r11= 24.010			
	d11= 2.281	N7= 1.83350	ν7= 21.00
r12= -90.639			
	d12= 2.743		
r13= -17.051			
	d13= 0.850	N8= 1.75450	ν8= 51.57
r14= -43.623			
	d14=15.155〜7.948〜1.200		
r15= ∞(絞りA)			
	d15= 0.100		
r16= 21.240			
	d16= 3.209	N9= 1.51823	ν9= 58.96
r17= -44.629			
	d17= 0.891		
r18= 23.330			
	d18= 4.839	N10=1.48749	ν10=70.44
r19= -36.872			
	d19= 1.199		
r20= -20.796			
	d20= 0.850	N11=1.84666	ν11=23.82
r21*=270.860			
	d21= 4.193〜0.937〜0.700		
r22= 23.066			
	d22= 3.862	N12=1.51742	ν12=52.15
r23= -18.159			
	d23= 1.524		
r24*=-35.189			
	d24= 0.850	N13=1.76743	ν13=49.48
r25*= 26.402			
	d25= 3.487		
r26= 48.817			
	d26= 1.623	N14=1.67339	ν14=29.25
r27=-167.772			

【００９９】[第７面(r7)の非球面データ]

ε = 1.0000

A4= 0.44355027×10^{-5}

A6= 0.37073814×10^{-7}

A8= -0.14298960×10^{-8}

A10= 0.13373838×10^{-10}

A12= $-0.41256179\times10^{-13}$

【０１００】[第２１面(r21)の非球面データ]

ε = 1.0000

A4= 0.10880422×10^{-4}

A6= 0.87297423×10^{-7}

A8= -0.46204110×10^{-9}

A10= $-0.16402917\times10^{-10}$

A12= 0.30793032×10^{-12}

【０１０１】[第２４面(r24)の非球面データ]

ε = 1.0000

A4= -0.69215309×10^{-5}

A6= -0.18251333×10^{-5}

A8= 0.65109565×10^{-7}

A10= -0.16403658×10^{-8}

A12= 0.15287778×10^{-10}

【０１０２】[第２５面(r25)の非球面データ]

ε = 1.0000

A4= 0.69987925×10^{-4}

A6= -0.15500116×10^{-5}

A8= 0.53872257×10^{-7}

A10= -0.12642621×10^{-8}

A12= 0.11335431×10^{-10}

【０１０３】図５～図７は、上記実施例１～実施例３のズームレンズにそれぞれ対応するレンズ構成図であり、広角端[W]でのレンズ配置を示している。各レンズ構成図中の矢印ｍ１～ｍ５は、広角端[W]から望遠端[T]へのズーミングにおける第１群Ｇｒ１～第５群Ｇｒ５の移動をそれぞれ模式的に示している。また、各レンズ構成図中、ri(i=1, 2, 3, . . .)が付された面は物体側から数えてi番目の面(riに*印が付された面は非球面)であり、di(i=1, 2, 3, . . .)が付された各群間の軸上面間隔は、物体側から数えてi番目の軸上面間隔のうち、ズーミングに

おいて変化する可変間隔である。

【０１０４】図８～図１０は、実施例１～実施例３にそれぞれ対応する収差図であり、各図中、[W]は広角端，[M]はミドル，[T]は望遠端における諸収差(左から順に、球面収差等，非点収差，歪曲；Y'：像高)を示している。また、各収差図中、実線(d)はｄ線に対する収差、破線(ＳＣ)は正弦条件を表しており、破線(ＤＭ)と実線(ＤＳ)は、メリディオナル面とサジタル面でのｄ線に対する非点収差をそれぞれ表わしている。

【０１０５】《比較例から実施例１への偏心誤差感度低減設計》先に述べたように、最近の技術では、ズーム群内で偏心が発生した場合、ズームブロックで調心を行うことにより、偏心収差の発生を抑えることが可能になっている。しかし、ズームブロックが傾いたり平行偏心を起こしたりした場合、可動群であるズームブロックの偏心を抑えることは難しい。そこで、ズームレンズ(比較例)に対して前記偏心誤差感度低減設計を行う場合の例を挙げて、第１～第５段階の具体的構成を説明する。なお、比較例(偏心誤差感度低減設計を行う前の状態)は、物体側から順に、正のパワーを有する第１群Ｇｒ１と、負のパワーを有する第２群Ｇｒ２と、正のパワーを有する第３群Ｇｒ３と、正のパワーを有する第４群Ｇｒ４と、から成り、各群の間隔変化によってズーミングを行う４群構成のズームレンズである。

【０１０６】〈第１段階〉まず、比較例の各ズームブロックの偏心誤差感度を光線追跡により調べて、偏心誤差感度が相対的に大きいために製造上問題となるズーム群を特定した(図３，＃１０)。表１に、比較例の各ズーム群が0.1mm平行偏心を起こした場合の望遠端[Ｔ]での偏心収差(言い換えれば偏心誤差感度)を示す。表１中、DM，DSはメリディオナル，サジタルの片ボケ収差、AXCMは軸上コマ収差をそれぞれ表しており、片ボケ収差は像高Y'＝-14.4での値を示している。表１から、第３群Ｇｒ３と第４群Ｇｒ４の偏心誤差感度が非常に大きいことが分かる。そこで、第４群Ｇｒ４を偏心誤差感度を小さくする群(ズームブロック)として特定した。

【０１０７】

【表１】

《比較例の望遠端[Ｔ]での各ズームブロックの偏心収差(mm)》

平行偏心：[偏心量]＝0.1mm

	DM	DS	AXCM
第１群	0.110	0.051	0.002
第２群	-0.063	0.076	-0.001
第３群	1.280	0.284	0.030
第４群	-1.217	-0.393	-0.031

【０１０８】〈第２段階〉次に、比較例の特定群である第４群Ｇｒ４の偏心誤差感度(偏心収差)を、偏心収差係数から計算した(図３，＃２０)。表２に、第４群Ｇｒ４とその像側群の３次収差係数を示す。左から順に、球面収差係数(I)，コマ収差係数(II)，非点収差係数(III)，ペッツバール和(P)，歪曲収差係数(V)である。第４群Ｇｒ４は最も像側のズーム群であるため、その像側群を有していない。したがって、像側群の３次収差係数は全て０である。表３に、[偏心量(0.1mm)]×[スペックの項]，各項についての[１次結合の係数]及び[偏心収差]の計算結果を示す。偏心収差係数は特定群の３次収差係数と像側群の３次収差係数との１次結合で表されるが、その１次結合の係数が各項の右欄の[１次結合の係数]である。また、表３中の第１項～第４項は、[偏心収差係数]の第１項～第４項に相当しており、その合計が最終的な[偏心収差]である。この合計値と実際の偏心収差(表１)との比較を行った(図３，＃２０)。

【０１０９】

【表２】

《比較例の特定群(第４群)と像側群の３次収差係数》

	(I)	(II)	(III)	(P)	(V)
特定群( )D	-8.5792×10^{-6}	-7.8172×10^{-4}	-3.284×10^{-2}	1.5194×10^{-2}	-0.7879×10^{-0}
像側群( )B	0	0	0	0	0

【０１１０】

【表３】

《比較例の望遠端[T]での第４群の平行偏心による偏心収差(mm)》

	DM	DS	AXCM		
	-E・FL・Y'	-E・FL・Y'	E・[(3・κ²・FL³)/(8・FNO²)]		
	223.776	223.776	2049.861		
第１項	0.000	0.000	0.000	(α'j-αi)	0.010
第２項	0.058	0.012	0.005	-αi	0.003
第３項	0.000	0.000	0.000	-(α'#j-α#i)	-0.249
第４項	-1.161	-0.387	-0.039	α#i	-2.213
合計	-1.103	-0.375	-0.034		
実際	-1.217	-0.393	-0.031		

【０１１１】〈第３段階〉２つの値を比較すると、偏心収差係数を用いた計算により得られた値と実際の光線追跡により得られた値とが非常によく一致していることが分かった。したがって、３次収差係数で偏心収差をコントロールすることができることになる。仮に、２つの値が大きくズレている場合、３次収差係数でコントロールしても実際の収差が小さくならない可能性があるので、その場合には偏心状態での点像を極小化する設計を行えばよい(図３，＃６０)。

【０１１２】表３から分かるように、軸上コマ収差(AXCM)の合計のほとんどすべてが第４項の値によるものである。軸上コマ収差の偏心収差係数の第４項は、偏心群(特定群)の球面収差係数(I)Dに[１次結合の係数]がかかったものである{式(6F)参照。}。片ボケ収差も第４項が支配的であり、片ボケ収差の偏心収差係数の第４項は、偏心群(特定群)のコマ収差係数(II)Dに[１次結合の係数]がかかったものである{式(5G)参照。}。したがって、第４群Ｇｒ４の平行偏心による軸上コマ収差を小さくするには、第４群Ｇｒ４の球面収差係数(I)Dを小さくすればよく、平行偏心による片ボケ収差を小さくするには、第４群Ｇｒ４のコマ収差係数(II)Dを小さくすればよいことが分かった(図３，＃３０)。

【０１１３】〈第４段階〉偏心誤差感度を大きくする主要因となっている３次収差係数を、上記第３段階で特定することができたので、これらを小さくする設計を行う(図３，＃４０)。具体的には、第４群Ｇｒ４の球面収差係数(I)Dとコマ収差係数(II)Dを小さくする。表４，表５に、３次収差係数(I)D，(II)Dを小さくする設計を行ったときの３次収差係数，偏心収差等を、表２，表３と同様に示す。表５から分かるように、第４群Ｇｒ４の球面収差係数(I)Dとコマ収差係数(II)Dが小さくなることで、軸上コマ収差と片ボケ収差が共に比較例と比べて格段に小さくなっている。

【０１１４】

【表４】

《比較例の３次収差係数(I)D，(II)Dを小さくした場合》

	(I)	(II)	(III)	(P)	(V)
特定群( )D	-1.4195 $\times 10^{-6}$	-1.6263 $\times 10^{-4}$	0.264 $\times 10^{-2}$	1.5638 $\times 10^{-2}$	1.8596 $\times 10^{-0}$
像側群( )R	0	0	0	0	0

【０１１５】

【表５】

《比較例の３次収差係数(I)D,(II)Dを小さくした場合》

	DM	DS	AXCM		
	-E・FL・Y'	-E・FL・Y'	E・[(3・κ²・FL³)/(8・FNO²)]		
	223.865	223.865	2052.295		
第１項	0.000	0.000	0.000	(α'j-αi)	0.010
第２項	-0.016	-0.012	0.001	-αi	0.003
第３項	0.000	0.000	0.000	-(α'#j-α#i)	-0.348
第４項	-0.247	-0.082	-0.007	α#i	-2.263
合計	-0.263	-0.095	-0.006		

【０１１６】〈第５段階〉上記のように第４群Ｇｒ４の３次収差係数だけを変化させると、全体の３次収差係数のバランスが崩れるため、偏心誤差感度は小さくなっても、満足な光学性能を得ることができないといった問題が生じる。そこで、変化させた第４群Ｇｒ４の３次収差係数をそのままにして、全体の３次収差係数の和が小さくなるように設計を行った（図３，＃５０）。具体的には、第３群Ｇｒ３の３次収差係数を大幅に変化させるために、第３群Ｇｒ３に非球面を追加して、すべてのズーム領域で満足な光学性能が得られるように設計を行った。第１群Ｇｒ１～第３群Ｇｒ３の３次収差係数を変化させても、第４群Ｇｒ４の偏心収差には影響が及ばないので、満足な光学性能と、第４群Ｇｒ４の偏心誤差感度低減と、を同時に達成することができた。

【０１１７】上記非球面を付加した設計後の状態が、上記実施例１である。表６に、その設計後の実際の偏心収差を、表１と同様に示す。表６から分かるように、意図していた第４群Ｇｒ４の偏心誤差感度低減と共に、第３群Ｇｒ３の偏心誤差感度も小さくなっている。表７に、比較例と実施例１の各ズーム群の望遠端[T]での３次収差係数の和を示す。全体の３次収差係数の大きさは共に小さいが、第３群Ｇｒ３と第４群Ｇｒ４の３次収差係数が、上述した設計後に小さくなっている点に特徴が見られる。

【０１１８】

【表６】

《実施例１の望遠端[T]での各ズームブロックの偏心収差(mm)》

平行偏心：[偏心量]＝0.1mm

	DM	DS	AXCM
第１群	0.105	0.052	0.002
第２群	0.018	0.097	0.000
第３群	0.175	-0.049	0.005
第４群	-0.291	-0.101	-0.007

【０１１９】

【表７】

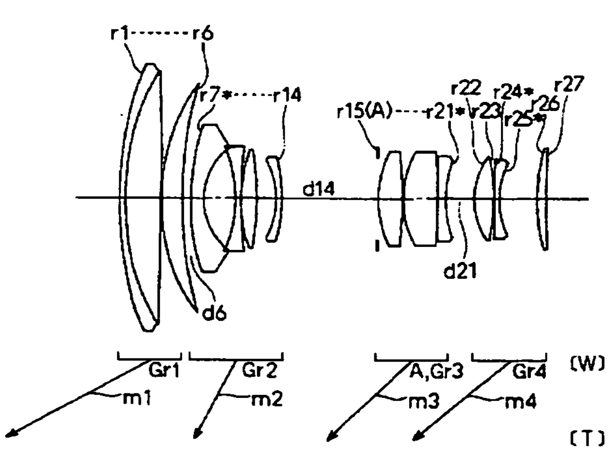
《比較例と実施例１の望遠端[Ｔ]での各ズーム群の３次収差係数の和》

収差係数		(I) $\times 10^{-6}$	(II) $\times 10^{-4}$	(III) $\times 10^{-2}$	(P) $\times 10^{-2}$	(V) $\times 10^{-0}$
比較例	第１群	1.1613	-1.8144	4.3567	1.0104	-12.7781
	第２群	-3.528	-0.6739	-6.1886	-4.7615	8.722
	第３群	11.057	10.307	5.111	2.341	-0.619
	第４群	-8.579	-7.817	-3.284	1.519	-0.788
	合計	0.111	0.002	-0.005	0.109	-5.463
実施例１	第１群	1.0889	-1.7327	4.2753	1.0017	-13.1635
	第２群	-1.5283	0.9903	-5.3488	-4.7081	8.8763
	第３群	1.829	2.783	0.749	2.176	-2.816
	第４群	-1.420	-1.626	0.264	1.564	1.860
	合計	-0.030	0.414	-0.061	0.034	-5.244

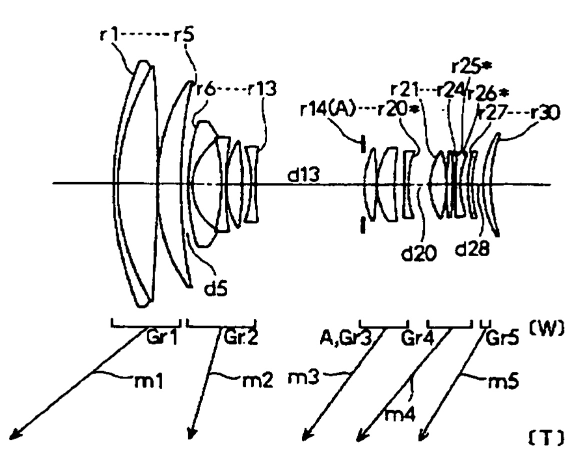
【０１２０】
【発明の効果】以上説明したように、本発明の光学系によれば、偏心誤差感度が相対的に大きい特定群に対し、偏心誤差感度を大きくする前記３次収差係数を小さくし、さらに収差バランスを整えた構成になっているため、特定群が非球面等を含むか否かにかかわらず、特定群の偏心収差の誤差感度が低減されて、良好な光学性能が達成される。また、本発明の製造方法，偏心誤差感度低減設計方法によれば、製造誤差で発生する偏心収差を小さく抑えて、良好な光学性能を有する光学系を得ることができる。

【図面の簡単な説明】
【図１】光学系と座標との関係及び収差係数を説明するための図。
【図２】偏心収差係数の導出を説明するための図。
【図３】本発明に係る偏心誤差感度低減設計の手順を示すフローチャート。
【図４】本発明に係る偏心誤差感度低減設計と従来の設計との違いを説明するためのイメージ図。
【図５】実施例１のレンズ構成図。
【図６】実施例２のレンズ構成図。
【図７】実施例３のレンズ構成図。
【図８】実施例１の収差図。
【図９】実施例２の収差図。
【図１０】実施例３の収差図。
【符号の説明】
Ｇｒ１　…第１群
Ｇｒ２　…第２群
Ｇｒ３　…第３群
Ｇｒ４　…第４群
Ｇｒ５　…第５群
Ａ　　　…絞り

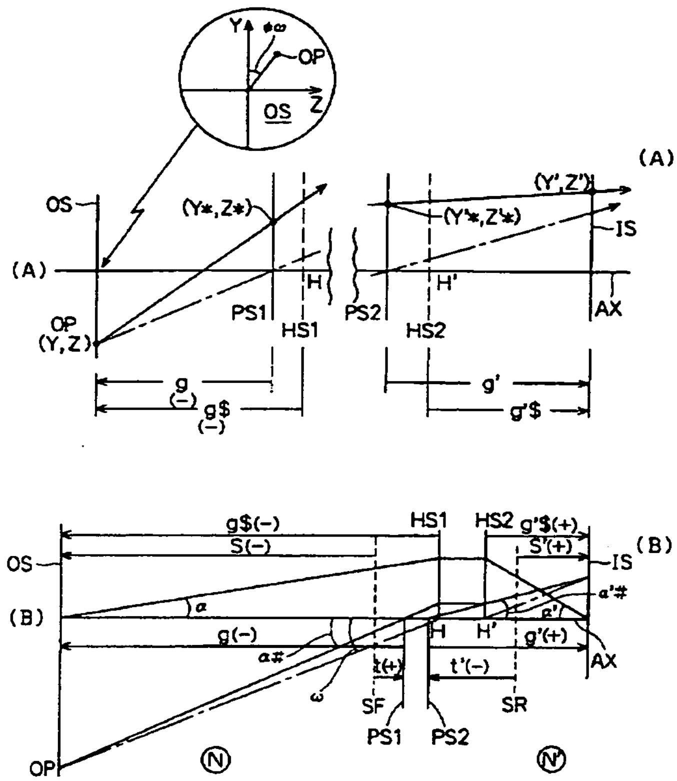
【図５】



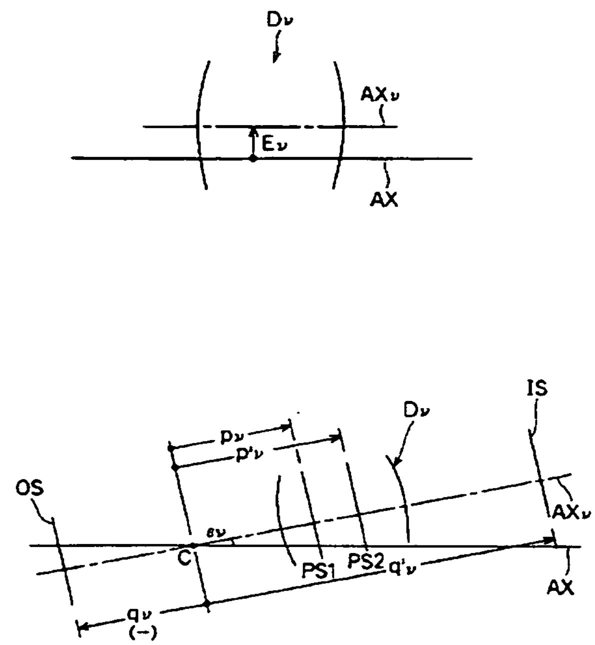
【図６】



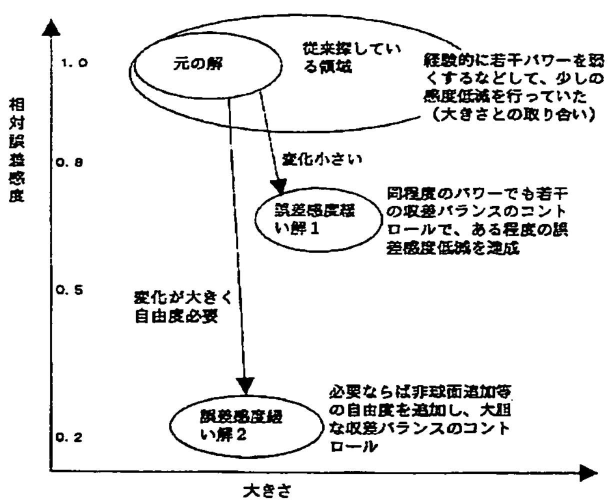
【図１】


Y
$\phi\omega$
OP
OS
Z
(A)
OS
(Y*, Z*)
(Y', Z')
(Y'*, Z'*)
IS
H
H'
PS1
HS1
PS2
HS2
AX
OP
(Y, Z)
g
(−)
g$
(−)
g'
g'$
g$(−)
HS1
HS2
g'$(+)
(B)
S(−)
S'(+)
IS
α
α'#
α'
g(−)
g'(+)
α#
t(+)
t'(−)
ω
SF
SR
PS1
PS2
OP
N
N'

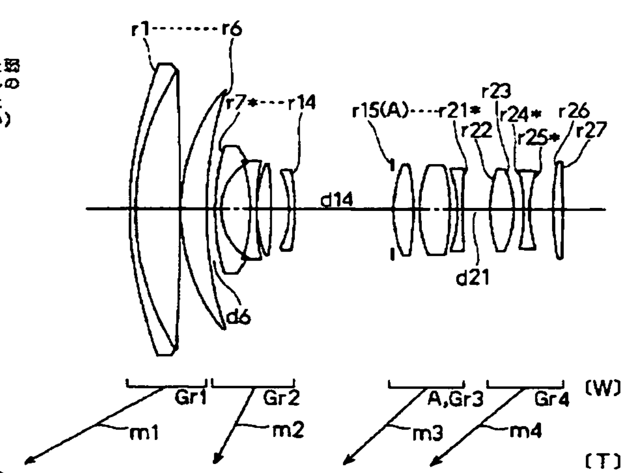
【図２】


Dν
AXν
Eν
AX
IS
Dν
pν
p'ν
OS
θν
AXν
C
PS1
PS2
q'ν
AX
qν
(−)

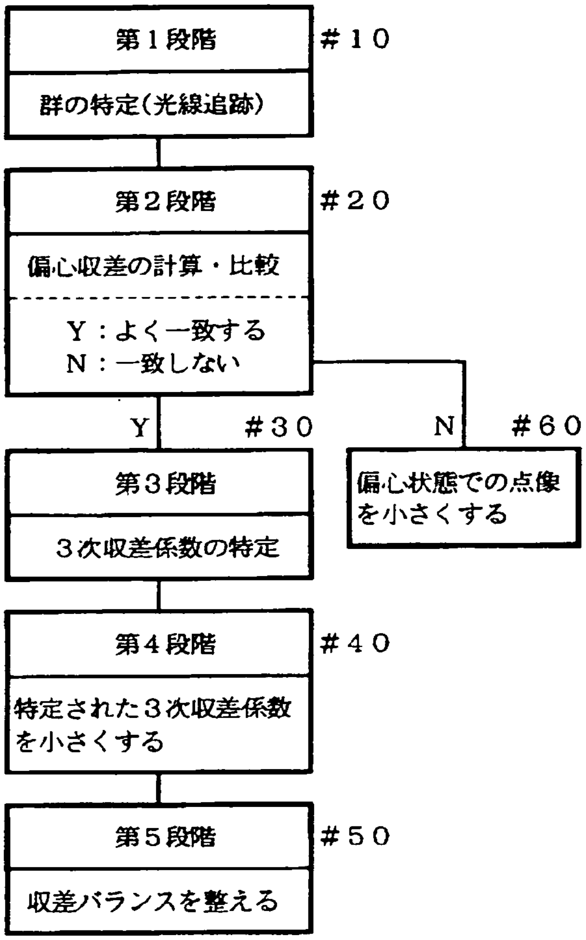
【図４】


相対誤差感度
1. 0
0. 8
0. 5
0. 2
元の解
従来探している領域
経験的に若干パワーを弱くするなどして、少しの感度低減を行っていた（大きさとの取り合い）
変化小さい
誤差感度緩い解１
同程度のパワーでも若干の収差バランスのコントロールで、ある程度の誤差感度低減を達成
変化が大きく自由度必要
誤差感度緩い解２
必要ならば非球面追加等の自由度を追加し、大胆な収差バランスのコントロール
大きさ

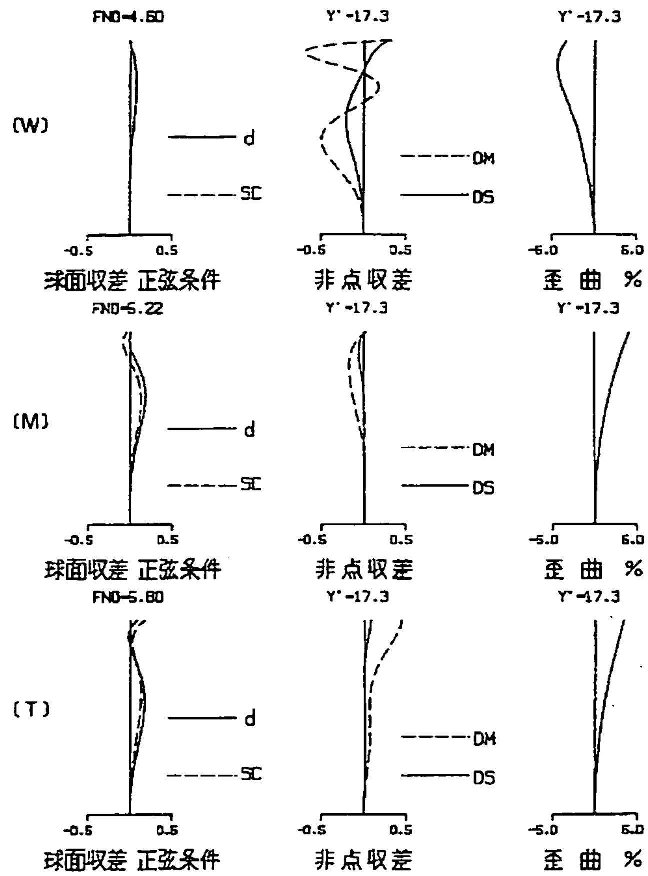
【図７】


r1--------r6
r7*---r14
r15(A)---r21*
r22
r23
r24*
r25*
r26
r27
d14
d6
d21
Gr1
Gr2
A,Gr3
Gr4
(W)
m1
m2
m3
m4
(T)

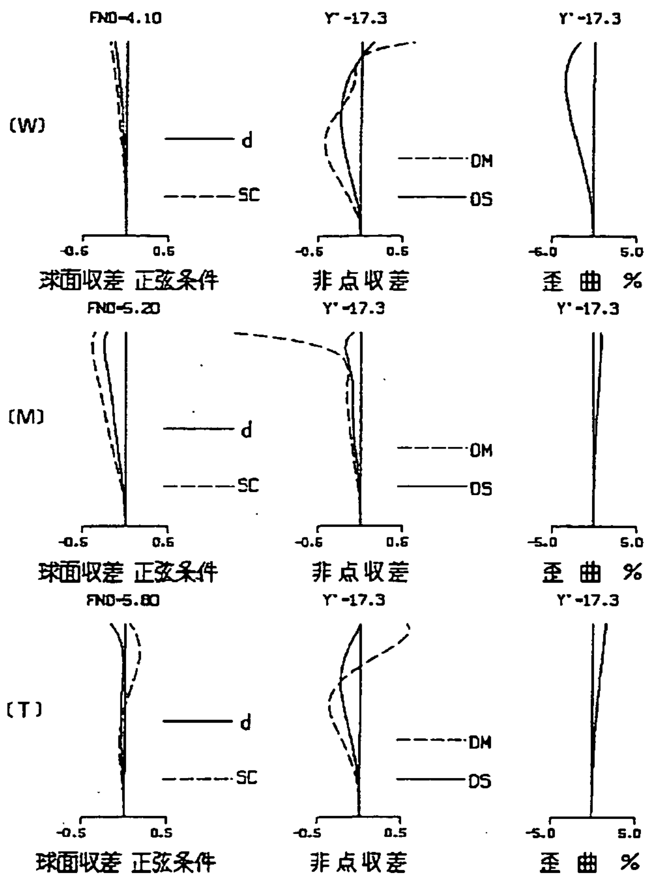
【図3】


第１段階
#１０
群の特定(光線追跡)
第２段階
#２０
偏心収差の計算・比較
Ｙ：よく一致する
Ｎ：一致しない
Ｙ
#３０
Ｎ
#６０
第３段階
３次収差係数の特定
偏心状態での点像を小さくする
第４段階
#４０
特定された３次収差係数を小さくする
第５段階
#５０
収差バランスを整える

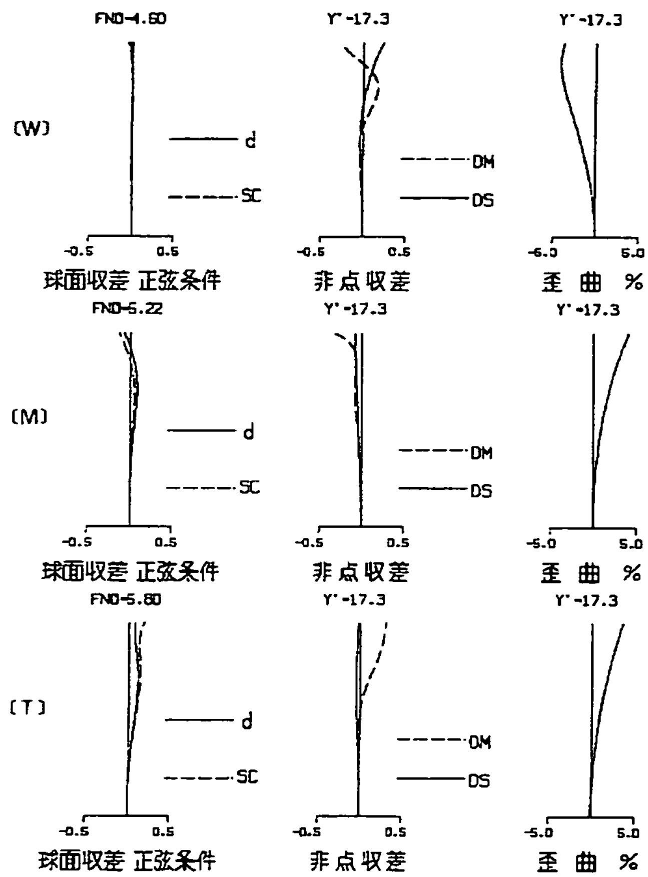
【図8】


FNO=4.60
Y'=17.3
Y'=17.3
(W)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-6.0 6.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.22
Y'=17.3
Y'=17.3
(M)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 6.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.80
Y'=17.3
Y'=17.3
(T)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %

【図9】


FNO=4.10
Y'=17.3
Y'=17.3
(W)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.20
Y'=17.3
Y'=17.3
(M)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.80
Y'=17.3
Y'=17.3
(T)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %

【図１０】


FNO=4.60
Y'=17.3
Y'=17.3
(W)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.22
Y'=17.3
Y'=17.3
(M)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %
FNO=5.80
Y'=17.3
Y'=17.3
(T)
d
SC
DM
DS
-0.5 0.5
-0.5 0.5
-5.0 5.0
球面収差 正弦条件
非点収差
歪曲 %